Physical Sciences for Canadian High Schools

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PHYSICAL SCIENCES
FOR CANADIAN
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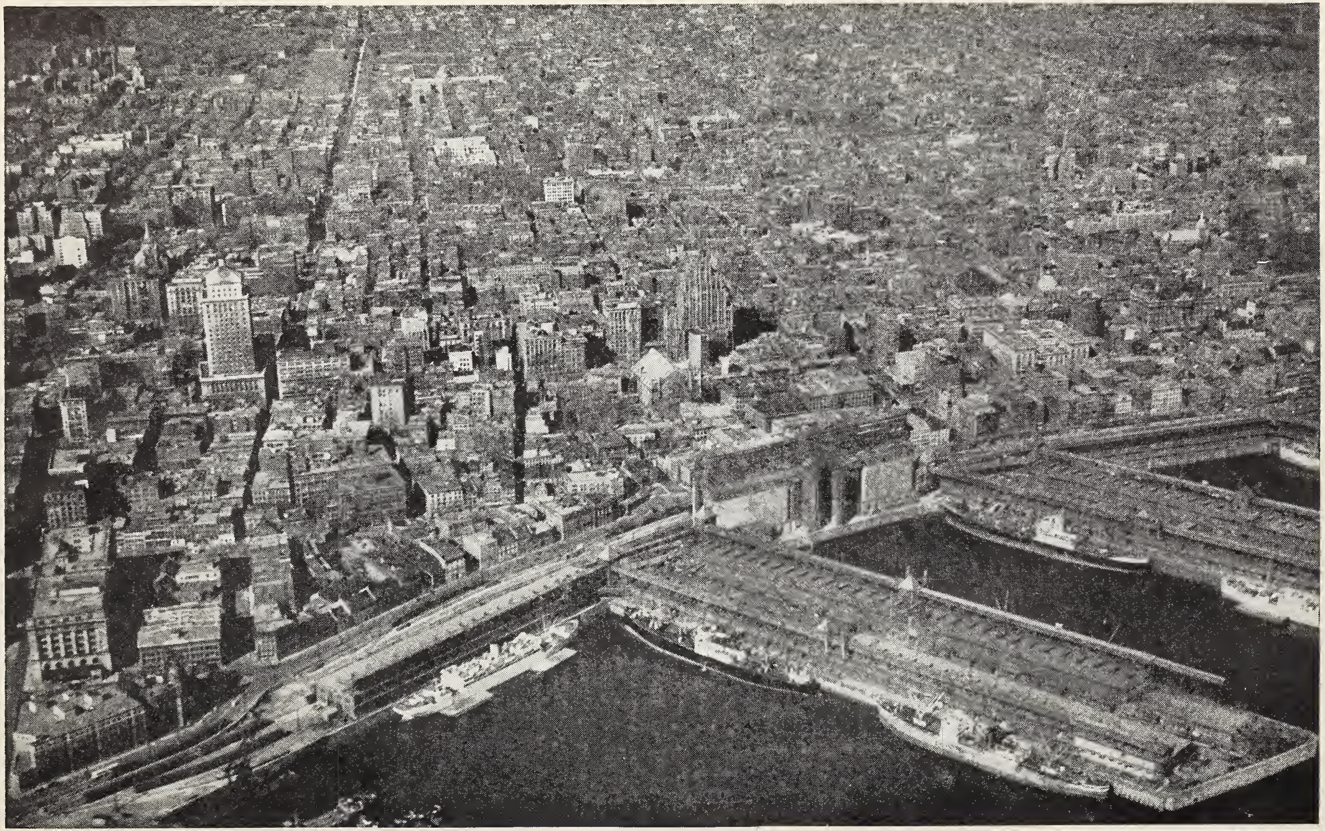

Courtesy National Film Board

The busy Montreal waterfront, with its crowded railroad sidings and its piers piled high with freight, emphasizes the importance of land and water communications in today's world.

PHYSICAL SCIENCES FOR CANADIAN HIGH SCHOOLS

By

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PREFACE

To be an intelligent and useful citizen in our modern world, a person cannot simply take for granted such natural phenomena as electricity, weather changes, the varied formations of the earth's surface, or the movements of the planets. He must try to understand these phenomena in order to appreciate their importance and influence upon our civilization. Nor should any of us merely accept such inventions as the automobile, television, the jet plane, and the atomic bomb without desiring some knowledge and understanding of why and how man was able to invent such valuable devices. In other words, everyone should know something about the basic principles and laws of physics, chemistry, geology, meteorology, and astronomy—the so-called physical sciences.

In developing their course in the physical sciences, the authors have selected *Combustion* as their unifying theme. The story of combustion is, in large measure, the story of the advancement of civilization. Combustion lends itself equally well to physics and chemistry, and, without straining the theme, to geology, astronomy, and atomic energy. This unifying theme correlates the various branches of science and permits a reasonably comprehensive treatment of them.

The course presented in this text has been developed over a period of eight years, during which time the students worked with mimeographed copies of the manuscript. It has been revised and amended each year in the light of classroom experience. This text represents the final version of the manuscript, which the authors believe is an interesting and teachable approach to the physical sciences.

The authors have tried to tell an interesting as well as a true story. They frequently use the historical or sociological approach and, of course, make constant reference to everyday phenomena.

The text is organized into eleven units, which are subdivided into related chapters. Though all units are essential to the course, the same amount of time need not be spent on each. At the end of each chapter is found a brief summary of "Things to Remember," followed by questions to test the student's knowledge. A longer list of Review Questions at the end of each unit serves as a test on the content of the unit as a whole. All the questions are arranged in two groups under the letters *A* and *B*, those under *B* being more exacting than those under *A*.

Throughout the text there are directions for numerous demonstrations. These demonstrations should be performed, not merely discussed. Students like to see things happen. If the demonstrations are well performed, they will stimulate the students to undertake the projects found at the end of most of the chapters. Some of the projects can be attempted by the class as a whole, others by individual students who are especially interested in particular subjects.

Reading lists at the end of the units give the titles of publications related to the unit just completed. The pamphlets can usually be obtained free from the companies that publish them. Like the questions, the publications are arranged in two groups under the letters *A* and *B*. Those under *A* will be found easier to read than those under *B*.

The authors gratefully acknowledge their indebtedness to many friends who, through correspondence or discussion, have made suggestions that have been incorporated in the text. They want to thank Dr. C. T. Lloyd, Chairman of the English Department of The Phillips Exeter Academy, for his meticulous reading and appraisal of the whole manuscript; Professor Alfred S. Romer of Harvard University for his critical reading of the geology unit; Mr. R. F. Brinckerhoff of The Phillips Exeter Academy for his helpful suggestions in the preparation of the astronomy unit; and Mr. R. L. Dunnell and Mr. R. Mayo-Smith of The Phillips Exeter Academy for their helpful comments and criticisms while using the mimeographed form of the text in their science classes.

J. C. H.
J. B. C.
E. P. L.

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SCIENCE AND HUMAN ACHIEVEMENT

1. EARLY PROGRESS
2. MODERN DEVELOPMENTS

Chapter 1

EARLY PROGRESS

In the Beginning. Human civilization began almost a million years ago, but its early development was extremely slow. Ancient man, like the animals, was struggling for existence. He had comparatively high intelligence and great strength. He learned how to make stone tools, including bludgeons, axes, and knives; with their help, he protected himself against wild animals, and even killed them for food. He lived a wandering life, staying in one place only as long as the hunting and fishing were good.

Man's principal food at this time was fresh meat. To get food he hunted animals, and he learned their habits and ways. Occasionally he captured stray animals; slowly he learned to domesticate them. This was particularly true of grass-eating animals such as sheep, oxen, and horses.

The domestication of animals was the first great step in the advance of civilization. This probably was accomplished about fifteen thousand years ago. When man could use animals to do his work, he slowly changed from a nomadic hunter to a settled farmer. He used oxen to till the soil and to drag sledges. He trained horses to carry packs on their backs. Later he learned to ride them. This was one of the first means of transportation.

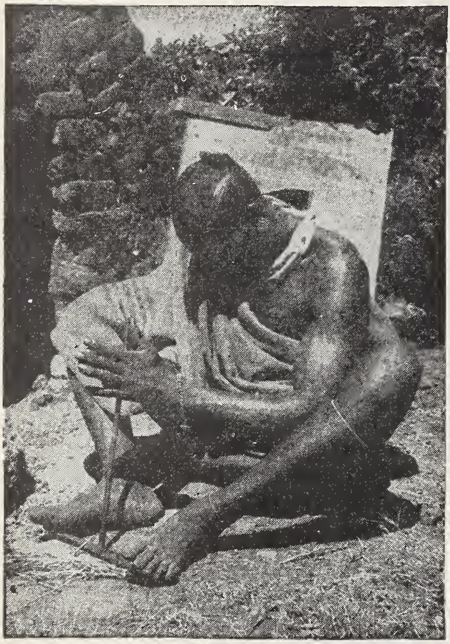
Modern transportation probably began about 3000 B.C., when some unknown genius invented the wheel. Then someone designed the combination of wheel and axle for carrying heavier loads. This unknown inventor served mankind well, for even today the wheel and axle plays an important part in transportation.

The Conquest of Fire. While primitive man was learning to use animal power instead of his own power he was also wondering how to control fire. For many centuries man was afraid of fire because he did not understand it. His first knowledge of it probably came from forest fires that were caused by lightning. He believed that such fires were started by an angry fire god, and it is not surprising that the worship of fire was a common practice among primitive tribes.

But man is intelligent. Eventually he succeeded in making fire himself. He learned two ways to start a fire. One way depended on the fact that when certain very hard rocks are struck against each other sparks are produced. The rocks used for this purpose were pyrites and flint. Pyrites is a mineral that contains iron but looks like gold; in fact it is sometimes called "fool's gold." The word *pyrites* is derived from a Greek word meaning "fire." Flint usually occurs as small masses in chalk. When flint and pyrites are struck against each other a shower of sparks is formed. If these sparks fall on a heap of dry grass or powdered bark, they may start a fire. The modern cigarette lighter is an adaptation of this ancient device. In the lighter, however, sparks are usually caused by steel striking against a hard substance called an abrasive.

Another way of making fire is shown in Fig.

1–1. It depends on the heat produced by friction between two pieces of wood. A straight stick, called a *drill*, is held between the hands so that its rounded end rests on a flat board. When the drill is rotated rapidly, hot wood dust collects in a groove in the board. The dust smolders. Air blown on these dust particles produces glowing embers. If these embers are then transferred to a tinder of dry grass or powdered bark, a fire may be started.



Ewing Galloway

Fig. 1–1. A native African woman making fire by friction.

It is clear that, for the ancients, fire making was a long, slow process. Therefore, once a fire was started it was kept burning continually because it was needed not only for warmth and for cooking food but also for keeping away wild animals, which feared it.

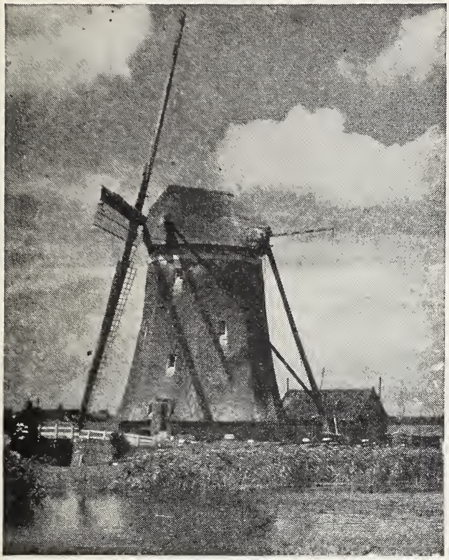
The friction method of starting a fire is still used by tribes in the interior of Africa and South America, and also in some of the Pacific islands. In our country even today the hunter and the woodsman sometimes use this method of starting a fire. Can you or one of your friends demonstrate this method?

Sources of Power. When early man learned to make fire either by striking two stones together or by rubbing one stick against another, he made one of his greatest discoveries. This discovery was a turning point in human history, for the ability to use fire has made civilization possible. The locomotive, the steamship, the automobile, the airplane, and most industrial processes, such as the manufacture of steel and cement, would not have been possible if man had not learned to make fire. Try to imagine life before the days of the steam locomotive and the steamship, that is, before the year 1800. There were few facilities for travel, and there was little machinery to aid man in his daily tasks. He traveled on horseback or by stagecoach, he used horses or oxen to plow his fields, and he crossed the ocean in sailing ships. He therefore knew little of the world outside his immediate neighborhood. Industry was on a small scale, because the means of manufacture and transportation were primitive

Water power and wind power were available, however, since water and wind are present in nature; they are not dependent on fire. The running water in a stream was used to rotate a wheel, which, in turn, was used to grind corn or to drive a machine. A windmill was less satisfactory as a source of power because it could operate only when the wind was blowing.

The American Pioneer. The early American colonists lived under comparatively primitive conditions. Little more than a century ago, the pioneer fought both nature and Indians in a grim struggle for existence. This rugged individual literally lived off the soil. First he felled trees and cleared his land of undergrowth and rocks. Then he tilled the earth, grew crops, and raised cattle and sheep. From the timber on his land he built a house and obtained fuel for heating and cooking; from his crops he provided food. He obtained wool from sheep, wove the wool into cloth, and in this way provided himself with clothing. He colored his cloth with dyes that he extracted from berries and roots growing on his land.

The pioneer needed little or no money to buy things; in a sense, he was independent of the outside world. But he paid a high price for his independence. He toiled from morning till night; he used all his time to provide the bare necessities of life. He was almost completely isolated from his fellow men. He had little leisure and little education; his life was one of little change or progress.



Courtesy Netherlands National Tourist Office

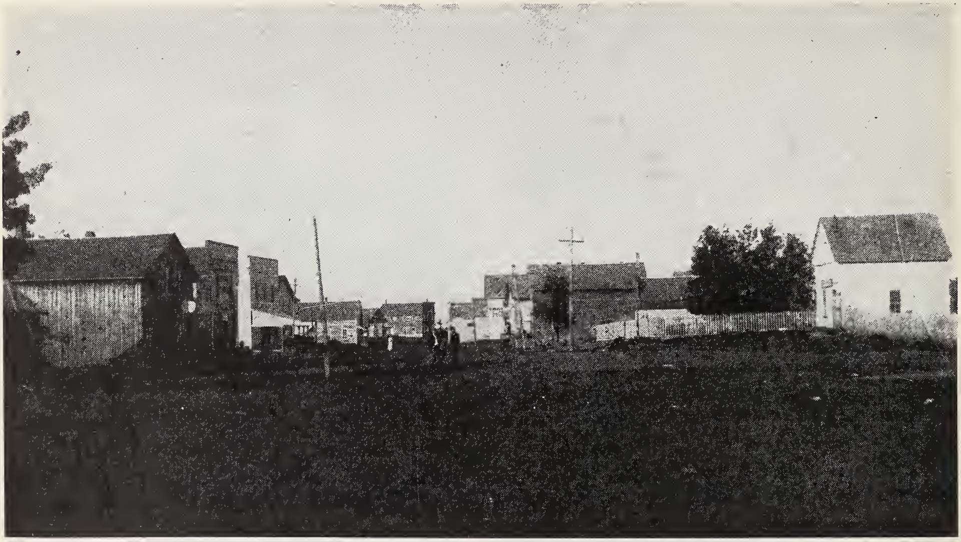
Fig. 1–2. Windmills are widely used in Europe today for pumping water and grinding grain. A modified form of this windmill may be seen on a number of farms in America.

The Industrial Revolution. Then came the *Industrial Revolution*, with all the fundamental changes that took place in the ways of living in the 18th and 19th centuries. Before the Industrial Revolution, goods were produced by human hands and transported by animals, helped only by the power of wind and water. During the Industrial Revolution *mechanical power replaced human power*. The introduction of mechanical power was made possible by the use of coal and by hundreds of inventions that completely altered the methods of manufacturing, mining, agriculture, and transportation.

The Industrial Revolution started in England, where there was an abundance of coal. Coal was used first only to heat houses; later it was used in the iron blast furnaces. Then, in 1769, came Watt's steam engine, which made it possible to get power from coal. Coal was used to boil water, and the resulting steam moved a piston up and down in a cylinder. But the really important thing about Watt's invention was that the moving piston was made to turn a wheel. The rotating wheel was then connected to machinery by means of belts, and the machines did the work. The steam engine was a great boon to industry. For example, in the textile industry the new steam power was applied to spinning and weaving. As a result, manufacturing was speeded up. Before the Industrial Revolution, textiles were so scarce and expensive that few workers could afford to buy the products they made. Now goods became so plentiful and inexpensive that many people could buy them.

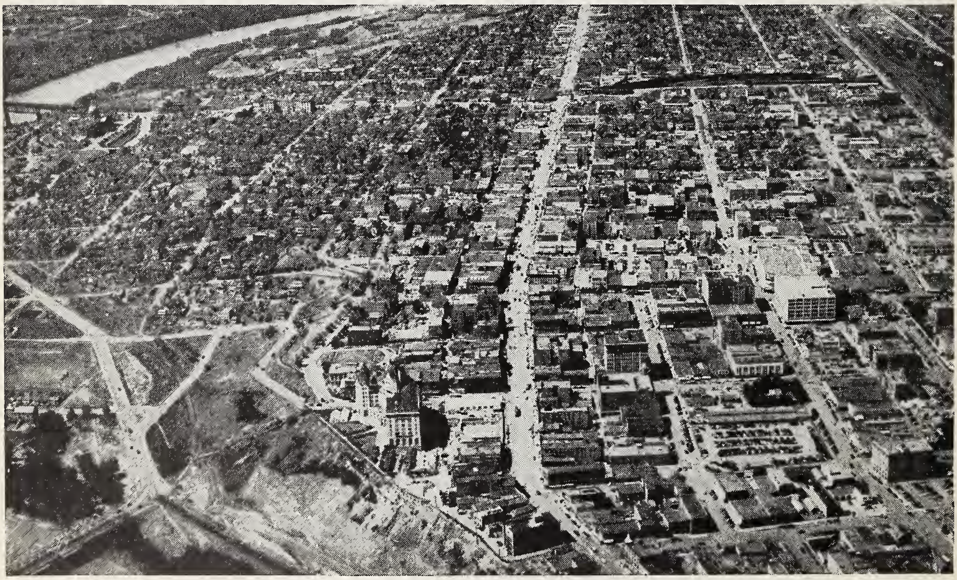
The Industrial Revolution in North America. When the first census was taken in 1790, the population of the United States was about four million. Only a few towns had a population of more than eight thousand. They included New York, Boston, Baltimore, Philadelphia, and Charleston—all situated on the east coast.

The mechanical inventions of the Industrial Revolution reduced hard manual labor



Courtesy Alberta Government

Fig. 1-3A. Edmonton, in 1890, was only a small village in the Northwest Territories. This is Jasper Avenue.



Courtesy Department of National Defense

Fig. 1–3B. Edmonton today. The wide street in the center of the photograph is Jasper Avenue.

and made industrial occupations more attractive; young people left the farms and small towns and flocked to the factories and shops in the cities. Immigrants from the Old World were also encouraged to settle in the new manufacturing centers, where they were easily absorbed by the rapidly expanding industries.

When Watt's steam engine, which was first used only with stationary machinery, was adapted to locomotives and ships, transportation on land and sea became more efficient. Coal supplied the power to transport the manufactured goods to all parts of the country. The expanding railway system between the industrial East and the farming regions of the West enabled the western cities to develop their own industries. Winnipeg became the funnel for this exchange of goods, built the world's largest rail yards and saw industry move west to take advantage of her location.

In 1890 Edmonton was a small village but when the railway came it could ship its coal throughout the West and soon grew in size as a distribution center. Now Edmonton has become the "Oil Capital" of Canada and the distribution point for this important fuel. Coal, oil, and natural gas are the raw materials of modern industry, and they will attract more plants and population. Edmonton is truly a "child" of the Industrial Revolution.

With hundreds of thousands of people concentrated in the cities, new ways of living resulted, and many social adjustments had to be made. A breakdown in industry was a serious thing for the workers; it resulted in unemployment and a shortage of such necessities as food, clothing, and shelter. To protect the workers against calamities of this sort, many laws were passed and many reforms were made to improve working and living conditions. Do you now understand why this period of sweeping changes is referred to as a "revolution"?

THINGS TO REMEMBER

Early man produced *fire* either by striking two stones together or by rubbing together two pieces of wood.

Water power and *wind power* were used before coal.

The *American pioneer* was economically independent, but he lacked the comforts and advantages of modern life.

The *Industrial Revolution*, in the 18th and 19th centuries, was brought about by the use of coal and machines. Industries expanded rapidly and cities grew around the industries.

James Watt, a Scot, invented the modern steam engine in 1769.

QUESTIONS

A

1. Name two early natural sources of power.

2. What is meant by the term *Industrial Revolution?*

3. Select an appropriate area in your locality. Note its essential location, resources and trace its industrial development.

B

4. Explain how primitive man started a fire by friction.

5. Explain why the domestication of animals was an important event in history.

PROJECT

To Start a Fire by Friction. Construct some apparatus for starting a fire by the friction between two pieces of wood. Directions can be found in the *Boy Scout Handbook.* Use this apparatus with suitable tinder to start a small fire. Also use steel and flint with suitable tinder to start a fire by friction.

Chapter 2

MODERN DEVELOPMENTS

The scope of the Industrial Revolution would have been greatly limited without railways. Before locomotives were invented, the transport of manufactured goods was restricted to poor roads and a few waterways. Rapid transportation of goods is as essential to industry as cheap manufacture.

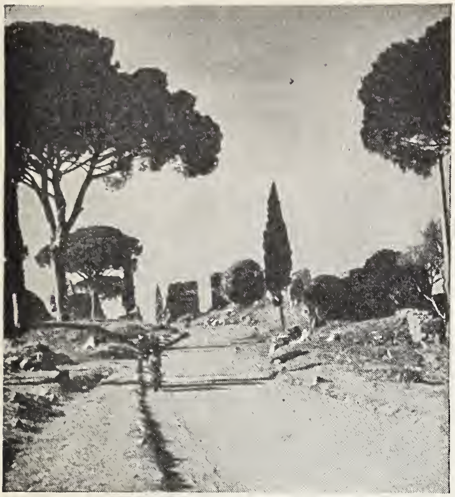
Roads. For many centuries, inland transportation of goods was limited to rivers and roads. The greatest road builders in early history were the Romans. The most famous road in their great empire was the Appian Way, begun about 300 B.C. The Appian Way extends from Rome to the Adriatic Sea. It is over 400 miles long. The construction of this paved highway was a gigantic enterprise. It took years to complete and required the labor of thousands of slaves. This road was of great strategic importance, for it gave Rome direct communication with southern Italy, Sicily, Africa, and Asia. It made possible the rapid transportation of reinforcements and supplies, and also the rapid transmission of news and messages. It provided a path for commerce which aided the peaceful development of the provinces. Over this most famous of all historical highways Julius Caesar, in pomp and splendor, rode in his chariot; St. Paul wearily trod its paved surface on his way to Rome to proclaim his Christian message.

After the construction of the Appian Way many other great roads were built, all radiating from Rome and extending to all parts of her empire. These roads were built straight across marshes, lakes, rivers, and mountains. Even judged by modern standards, they were great engineering feats. During the Middle Ages, the Roman roads were allowed to deteriorate. It was not until the early part of the 19th century that road building in Europe was resumed.

In the 20th century, the automobile raised new problems in road construction. Today our modern roads far surpass those of two thousand years ago. The concrete highways in the United States must bear the heavy burden of modern traffic and do this with a road surface only one-sixth as thick as that of the Roman roads.

Inland Waterways. In the 17th and 18th centuries, a system of canals was developed, particularly in Europe, to facilitate the transfer of goods. Goods were usually carried on barges towed by horses that walked along the side of the canal. Although transportation was slow, enormous loads of coal were carried from mine to factory at low cost.

In this country, great impetus was given to the development of inland waterways by Robert Fulton's invention in 1807 of the first practical steamboat, the *Clermont,* which traveled the Hudson River between New York and Albany. The Erie Canal, which made a water connection betweeen New York City and the Great Lakes, was completed in 1825. The canal is almost 350 miles long; it connects

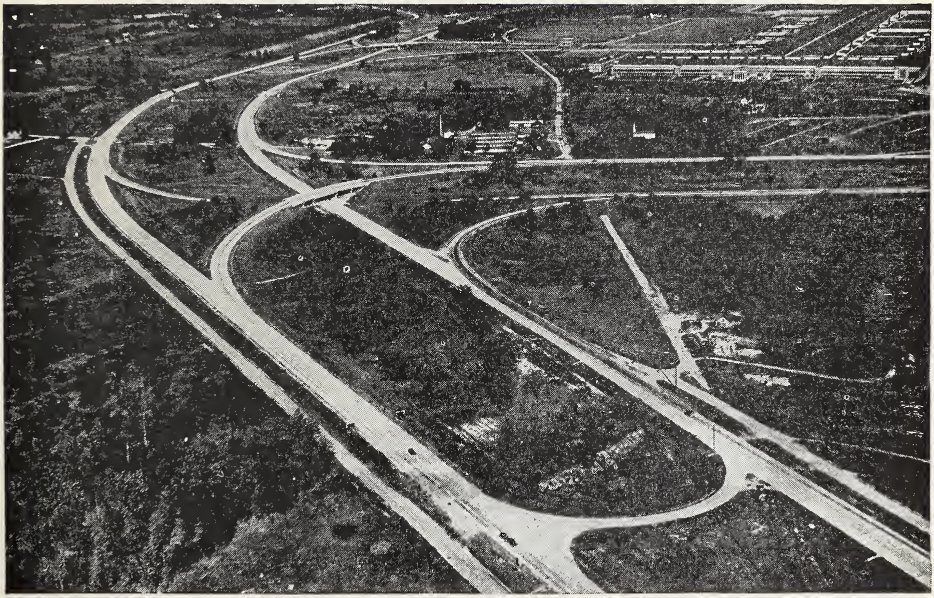


Courtesy Italian National Tourist Office

Fig. 2–1A. The Appian Way, as it looks today, typifies the skill of the ancient road builders.

Albany on the Hudson River with Buffalo on Lake Erie. The canal became a main route for transporting grain and cattle from the Midwest to the East. It also opened up the sparsely populated inland regions. Within the next decade, the populations of Rochester, Buffalo, Syracuse, and Utica were almost tripled. As trade increased and passenger facilities were improved, traffic on this and other inland waterways grew in importance. In 1918, the Erie Canal was deepened and widened. Horse-drawn barges are now replaced by powerful Diesels that propel ocean-going craft. Lake Erie, the western terminus of the canal, has become one of the greatest industrial waterways in the world.

Another important canal connects Houston, Texas, with the Gulf of Mexico. Houston was once a landlocked city fifty miles from the sea. Now it is a busy ocean port; indeed, it is the fourth largest in the United States (surpassed



Abrams Aerial Survey Corp.

Fig. 2–1B. A modern four-lane concrete highway that bears the burden of heavy present-day traffic. Its surface is only one-sixth as thick as that of the Appian Way.

only by New York, Philadelphia, and Baltimore). Nine oil refineries, the world's largest tin smelter, and many factories that manufacture heavy chemicals and plastics have been constructed near the canal.

Rivers are natural inland waterways. The Mississippi River is probably the most important one. It serves cities as far apart as Minneapolis, St. Louis, Memphis, and New Orleans. By the Ohio, Missouri, and other branches of the Mississippi River system, Pittsburgh, Cincinnati, Omaha, Kansas City, and other cities have access to the sea. Can you name other rivers used as water highways?

Railways. The canal systems greatly improved the speed and reduced the cost of long-distance transportation. But canal transportation was soon faced with the competition of railways. By 1860, trains were running regularly between Boston, New York, Philadelphia, and Baltimore. The railways were also rolling as far west as Cleveland, Chicago, Cincinnati, and St. Louis. Travel time was reduced from weeks to days, and the cost of carrying freight from dollars to cents. Freight consisted not only of manufactured goods but also of fresh fruits and vegetables, which now could be sold hundreds of miles from the orchards and farms where they were grown.

Steamships. The success of Fulton's river boat stimulated the construction of ocean-going steamships. The first steamship crossed the Atlantic in 1819. Actually it was a combination of steam and sailing ship. The two pictures on page 12 show the great progress made in marine engineering within a century.

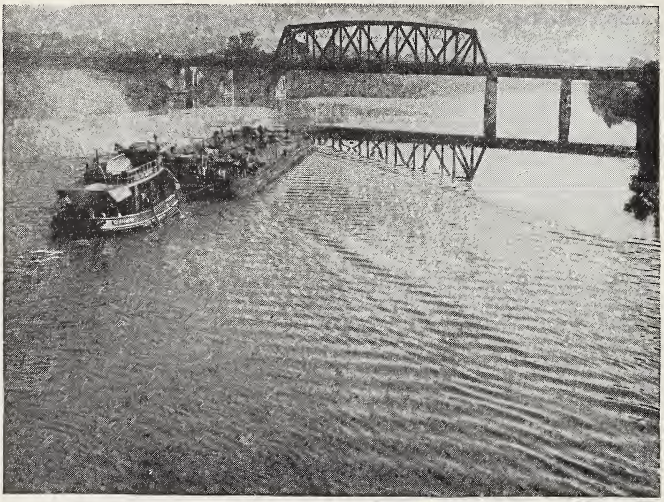
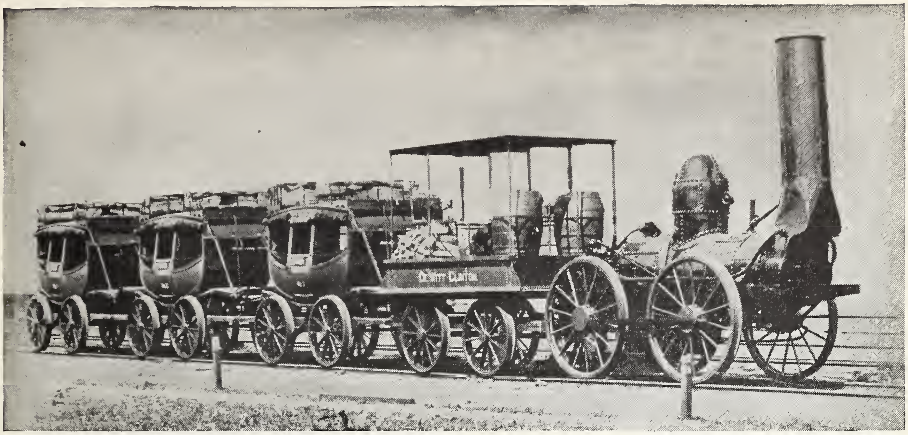

Courtesy Standard Oil Co. (New Jersey)

Fig. 2–2. The Erie Canal, opened in 1825, now accounts for over 16,000,000 tons of shipping a year.

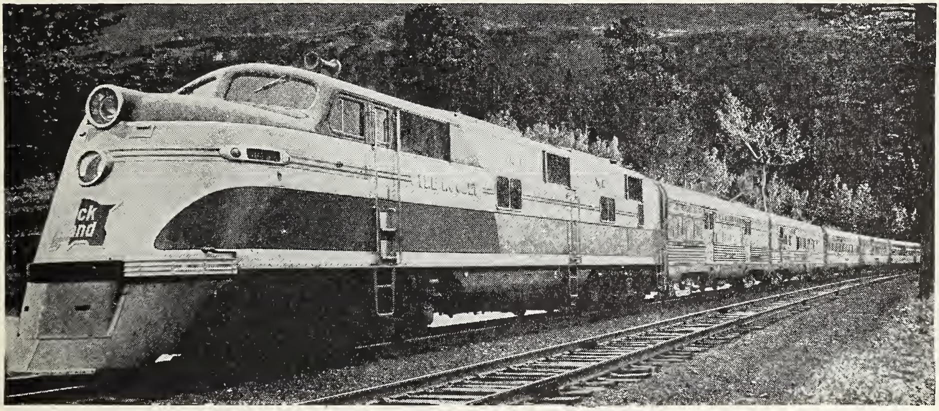
Automobiles and Airplanes. Since 1900 transportation has been revolutionized by the automobile and the airplane. The first American-made automobile was built in 1893, but because of its mechanical imperfections and the lack of good roads, the importance of this "horseless carriage" was not at once recognized. Indeed, the insignificant role played by automobiles at the turn of the century is reflected



Courtesy New York Central System

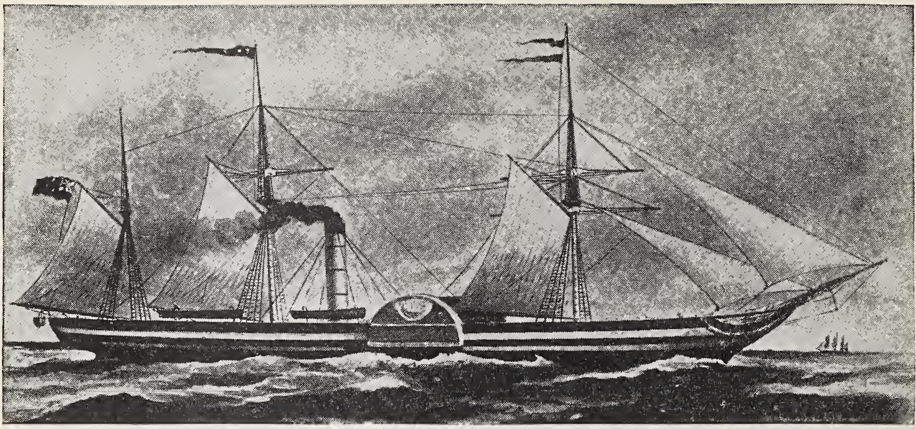
Fig. 2–3A. *The DeWitt Clinton* was the first locomotive to run in New York State. It carried passengers between Albany and Schenectady in 1831. Because of its crude construction, flying embers from the engine frequently ignited the passengers' clothing.

in the following amusing press release issued in 1899: "Three automobiles have been purchased by the War Department for the use of officers. Each is equipped so that a mule may be hitched to it should it refuse to run." It was not until 1908 that the automobile industry got under way and large-scale production began. In the relatively few years since that time the automobile has ceased to be regarded as an untrustworthy and dangerous curiosity and in this country is considered a necessity by millions of American families. According to the most recent available figures there are now registered in the United States more than



Courtesy Chicago, Rock Island and Pacific Railway

Fig. 2–3B. The Rock Island's *Rocket*, a modern streamlined passenger train, noted for its speed and comfort.

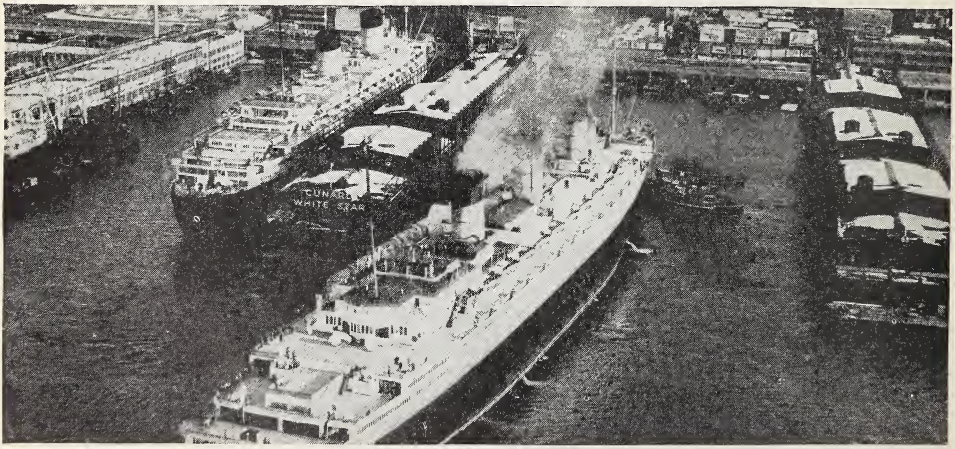


Courtesy Cunard White Star, Ltd.

Fig. 2–4A. The transatlantic ship *Britannia,* built in 1840, had paddle wheels and auxiliary sails. Its speed was rated at 9 knots; its gross tonnage at 1,139. It had accommodations for 115 passengers.

40,000,000 motor vehicles of all types, of which over 35,000,000 are passenger cars.

The rapid development of the airplane constitutes an equally amazing chapter in the story of transportation. About fifty years ago (in 1903, to be exact) the first airplane to carry a man aloft rose at Kitty Hawk, North Carolina. Orville Wright, lying flat on one of the airplane's wings while his brother Wilbur ran alongside to steady the plane, was the first man to fly a heavier-than-air plane. On its first flight the plane reached an altitude of only 10 feet and covered a distance of 120 feet in 12 seconds—an average speed of nearly



Courtesy Cunard White Star, Ltd.

Fig. 2-4B. The *Queen Elizabeth*, world's largest liner, and the *Queen Mary*, world's fastest liner, in dock at New York.

7 miles an hour! Nevertheless, the Wright brothers had discovered the secret of making a heavier-than-air machine travel through space. From this modest beginning, aviators have learned to take their machines more than 40,000 feet above the earth's surface and to propel them at speeds close to 1,000 miles an hour.

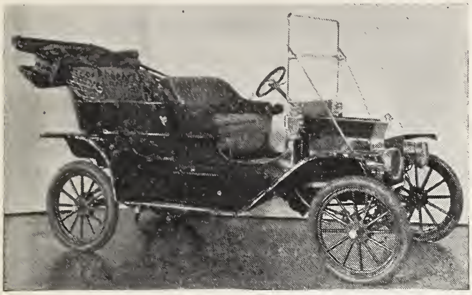

Courtesy Ford Motor Co.

Fig. 2–5A. This 1908 model-T was considered a rare luxury in the early 1900's.

Oil and Electricity. When we think of planes we are reminded that coal is no longer the main source of power in transportation. The 19th century was the age of coal; the 20th century thus far has been the age of oil and electricity. Oil and electricity came into use at the end of the 19th century, and both are indispensable in our present-day civilization.

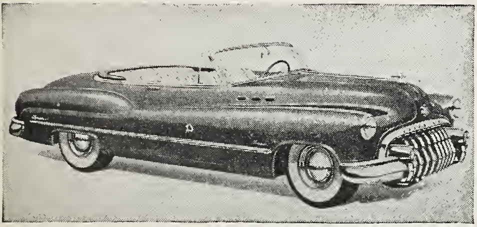

Courtesy General Motors Corp.

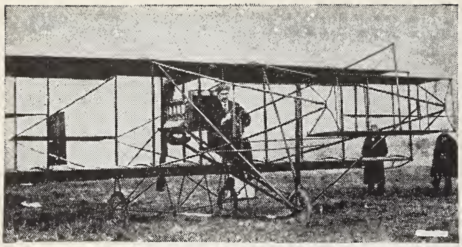
Fig. 2–5B. A late model Buick which illustrates the great advances made in automotive design and engineering in a period of less than fifty years.

With electricity the problem of transportation is simplified. Electric locomotives do not have to carry their own fuel. The source of power, the electric current, is carried on a transmission line. But the chief advantage of electricity is that it can be carried by overhead wires to country districts and to distant places, where it can be used for light, for heat, and for power in factories. It is no longer necessary to haul bulky fuels long distances.

Oil power is in evidence all about us. Most ships have long since ceased to use coal because oil is a cleaner and far more convenient fuel. Neither the automobile nor the airplane could have been developed without ample supplies of fuel oil (which includes gasoline, as you will learn later). You may wonder whether the airplane and the automobile will cease to operate when the world's limited oil supply is exhausted. Fortunately, chemists have learned to make substitutes, so that we are no longer completely dependent on the natural supplies of oil.

The Effect of Fuels and Machines on Our Own Civilization. When we compare our way of life with that of the American pioneer, we realize that startling changes have occurred within the past two centuries. Yet our basic needs are exactly the same as the pioneer's: food, clothing, and shelter. The activities of the pioneer were so varied that he did few of them well; ours are so concentrated that we become fairly expert in a single type of work. He was self-sufficient and depended on no one; we are dependent on our fellow men for the many activities in which we have no skill. He was completely occupied in making a living; we have time for education and recreation.

Modern civilization depends on transportation which enables the easy exchange of raw materials among nations. Consider, for example, the origin of a few common articles in the home. Meat and cereals probably come from the Midwest, timber may come from



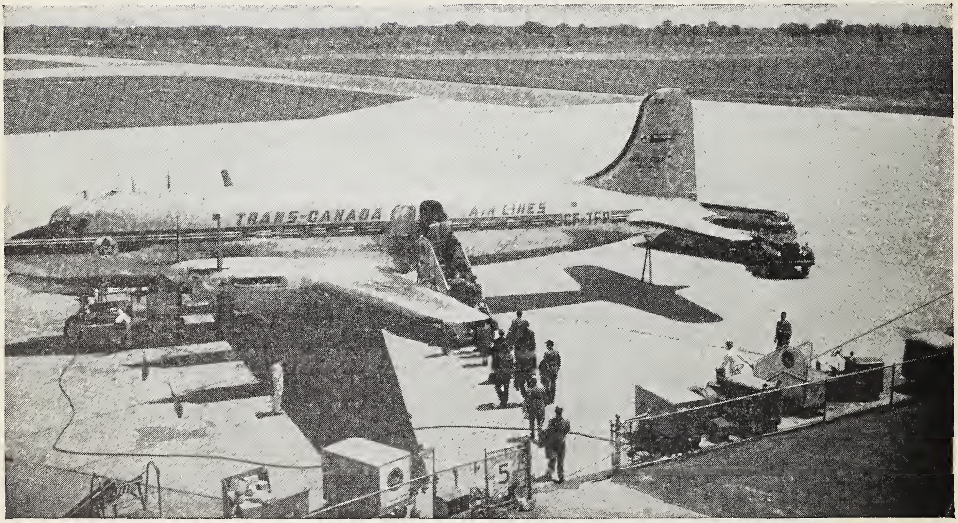
Courtesy United Air Lines

Fig. 2–6A. The *Kitty Hawk* with Orville Wright at the controls. First flown in 1903, this plane was barely able to leave the ground and stayed aloft for only a few seconds.

Canada, steel from Pittsburgh, rubber from Malaya, silver from Mexico, wool from Australia, linen from Ireland, tea from Ceylon, coffee from Brazil, oranges from California or Florida, fuel oil from Texas, and coal from Pennsylvania. This complex system would be impossible without fuels, which are the basis of power machinery and transportation.

Atomic Energy. The first half of the 20th century is known as the age of oil and electricity; the second half may be known as the age of atomic energy. The end of World War II was hastened by the use of atomic bombs. The first atomic bomb was exploded in New Mexico as an experiment. The second and third bombs were exploded over Japanese cities; they caused such destruction that the whole world stood aghast at the power of this new type of explosive.

These explosions were important, not because Japanese cities were destroyed, but because for the first time man was able to release energy from matter. Scientists had known for many years that some of the matter that makes up atoms could probably be changed into energy. They succeeded in releasing energy from matter when the atomic bombs exploded. In other words, energy was generated without the use of common fuels or chemical explosives.



Courtesy Trans-Canada Air Lines

Fig. 2-6B. From its humble beginning with the *Kitty Hawk* air travel has progressed to luxurious planes similar to this forty passenger *North Star*, which cruises at 250 miles per hour and flies at altitudes of 17,000 to 22,000 ft.

It is natural that we look on this new source of power with some apprehension. Will atomic energy be used for destructive or constructive purposes? Will it become a master or a servant? Are we approaching another industrial revolution? Will atomic energy replace oil and coal? Will it be possible to use the energy in a small piece of matter to drive large liners across the Atlantic? Can atomic energy be used to drive the machinery of factories? Will mining for coal and drilling for oil be unnecessary in the near future? Will atomic energy be available for all men in all nations? Will it raise standards of living throughout the world?

Scientific advances often initiate social changes. The changes that made the greatest impression on the writers of the 19th century were the increased production and lowered cost of manufactured goods and, above all, the opportunities for the advancement of the common man. One man, writing of England in the 19th century, in a booklet called *The Results of Machinery*, expressed it this way: "Two centuries ago, not one person in a thousand wore stockings; one century ago, not one in five hundred wore them; now, not one person in a thousand is without them."

When we look ahead to the year 2000, we may feel fairly certain that further great changes will have taken place in our social structure and will have outmoded many aspects of our present way of life.

THINGS TO REMEMBER

The Romans were the greatest road builders in early history. Many roads radiated from Rome, the most famous of which was the *Appian Way*.

Inland waterways were developed in Europe in the 17th and 18th centuries.

The *Erie Canal*, completed in 1825, helped to open up the Midwest.

The development of *railways* made the canals less important.

Robert Fulton built the first successful *steamboat* in 1807.

Orville Wright flew the first *airplane* at Kitty Hawk, North Carolina, in 1903.

Oil and electricity were first used for power at the end of the 19th century.

Atomic energy is obtained from the destruction of matter and not from common fuels.

Modern civilization depends on transportatio which enables goods and raw materials to b freely exchanged.

QUESTIONS

A

1. What was the importance of the Erie Canal?

2. Who were: (*a*) Robert Fulton; (*b*) Orville Wright?

3. Name six cities on inland waterways, stating also the canal or river on which each city is situated.

B

4. Where is the Appian Way, and why was it important?

5. How does life in the 20th century differ from that of the American pioneer?

6. Discuss some of the beneficial effects of the proposed St. Lawrence Seaway.

7. (*a*) When and where did the early development of the railways take place in Canada?
   (*b*) How did the development of the railways influence travel and commerce? What effect did freight transportation by rail have on our eating habits?

Unit 1

THE NATURE OF THINGS

3. ATOMS AND MOLECULES
4. MOLECULES IN MOTION
5. AIR, AN IMPORTANT MIXTURE
6. WATER, AN IMPORTANT COMPOUND
7. WATER FOR MACHINES

LYDIA

Chapter 3

ATOMS AND MOLECULES

If we drop a lump of sugar into water, the sugar gradually disappears; we say it has dissolved in water to form a solution. This, of course, is merely a statement of a common observation. But what has happened to the solid sugar? The sugar has disintegrated into small particles that we can no longer see. And what has happened to the small particles of sugar? We know that if we extract one drop of solution from *any* part of it, the drop will taste sweet. In other words, the particles of sugar are everywhere throughout the solution. How is it possible for sugar particles to spread throughout the water? There must be spaces in the water into which the sugar particles can penetrate. Water, however, *appears* to be continuous and, even under a powerful microscope, the spaces cannot be seen.

The above argument is quite logical, but it shows that things are not always what they seem to be. This was known to the Greek philosophers as early as 400 B.C. One of the philosophers named Democritus even went a step further than this. He said that all substances, whether solids, liquids, or gases, have holes in them, and that these holes are spaces between the particles that make up matter. These particles he called *atoms.* (The word *atom* comes from a Greek word meaning "cannot be cut.") Expressed more briefly, his idea was: *all substances are made up of atoms.*

What, then, are atoms? This tantalizing question has puzzled scientists through the ages. The Greeks, however, would have answered the question without hesitation by saying that atoms are nature's building blocks; they are used to build matter just as rocks are used to build temples.

Elements and Compounds. We shall say more about atoms a little later, but first let us return to sugar. If we heat some sugar strongly, it becomes considerably smaller. Eventually it chars so that we are left with a black residue. We can treat this residue with all the chemicals in the laboratory, but we cannot break it down into anything simpler. It is an *element*—the element carbon. After the rough treatment we gave the carbon we can say that an element is a substance that cannot be decomposed by chemical treatment. *An element is made up of atoms of the same kind.*

To date, ninety-eight elements have been discovered. You are probably familiar with some of them, such as iron, aluminum, sodium, mercury, carbon, oxygen, and chlorine. The first four are *metals,* the others *nonmetals.* Iron, aluminum, and sodium are *solids;* mercury is a *liquid;* oxygen and chlorine are *gases.* By far the most plentiful element on the earth is oxygen. What do you guess is the most plentiful metal? Although most people seem to believe it is iron, the correct answer is aluminum.

Let us return to the heating of the sugar. We discovered that the sugar got smaller and became charred. Why did the sugar get smaller? Part of it was lost because it escaped into the air. In other words, sugar *decomposes* when it is heated. Sugar therefore consists of some other element besides carbon; it is a *compound.*

Compounds form a large group of substances, tens of thousands of them. They are all around us. Salt, water, cotton, starch, and chalk are common compounds. *A compound is formed when atoms of different elements are linked together.* Sometimes only two elements form a compound, but there may be three, four, five, or even more. Sugar, for example, contains the elements carbon, hydrogen, and oxygen.

Let us now examine a few common compounds and the elements they contain.

Demonstration 3–1. Elements and Compounds.

Place each of the following elements and their corresponding compounds in bottles and arrange them in four groups as shown below:

	Elements	*Compounds*
1.	carbon and chlorine	carbon tetrachloride
2.	sodium* and chlorine	sodium chloride
3.	hydrogen and oxygen	water
4.	carbon, hydrogen, and oxygen	sugar

In the first example, carbon is a black solid and chlorine is a greenish-yellow gas; the compound carbon tetrachloride is a liquid. In the second, sodium is a silvery solid, while the compound sodium chloride, usually called common salt, is a white solid.

It is interesting to note that sodium is a poisonous metal and chlorine is a poisonous gas, but sodium chloride is not poisonous and is an essential part of our diet. Oxygen and hydrogen are gases, but the compound of these gases is water, a liquid.

There is no visible sign of an element in a compound; once the elements combine to form a compound, their properties are entirely changed. That is why we speak of a *chemical change.* A simple experiment will demonstrate this.

Demonstration 3–2. To Make a Compound from Its Elements.

Make a mixture of 10 grams of powdered iron and 5 grams of powdered sulfur. After a thorough mixing, pour enough of the mixture into a test tube to fill it halfway and keep the rest of the mixture separate. Support the test tube as shown in Fig. 3–1.

Now heat the bottom of the test tube in a Bunsen flame and, when the mixture begins to glow, remove it from the flame. The red glow spreads throughout the mixture as the chemical change takes place. Allow the test tube to cool.

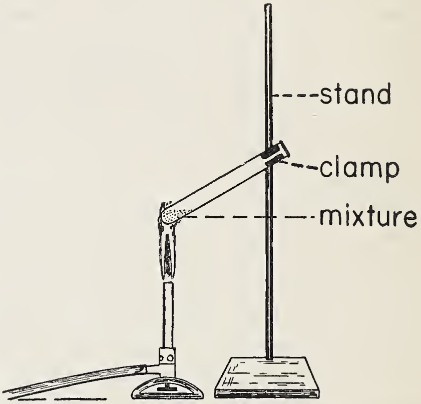


Fig. 3–1. Iron and sulfur combine when heated.

When it has cooled, remove the compound from the test tube, breaking the tube if necessary. Compare this compound with the mixture of iron and sulfur.

Notice that there is no trace of yellow sulfur in the compound. To show that there is no free iron in the compound, hold a magnet first near the compound, then near the *mixture.* The marked difference in the attraction by the magnet proves that there is little or no free iron in the compound.

We must be careful not to confuse the terms *compound* and *mixture.* The parts of a compound have reacted chemically, whereas the ingredients of a mixture have not. It follows that the substances in a mixture can be more easily separated than the same substances in a compound. In the mixture, iron and sulfur can be separated from each other quite easily; in the compound, the elements have combined and therefore cannot be easily separated.

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* The metal sodium must be kept in a bottle containing kerosene, otherwise it reacts chemically with the air. *Never* put sodium in water.

The compound formed in the demonstration is called iron sulfide. We can represent this chemical change by an equation:

$$\text{iron} + \text{sulfur} \rightarrow \text{iron sulfide}$$

This is read, "Iron and sulfur yield iron sulfide."

Obviously, there is some kind of bond holding the parts of the compound together. What does this bond look like? Do all atoms have bonds? These questions will be answered on pages 22–23. But first we must learn more about atoms.

Atoms. The Greek philosophers knew little or nothing about chemical reactions. Indeed, they made use of the experimental method only very rarely. A Greek gentleman did not like to soil his hands in a laboratory; he usually only meditated on the nature of things. It is therefore not surprising that as a result of our experimentation today we know considerably more about atoms than did the Greek philosophers. We know that atoms are so tiny that no microscope has sufficient magnifying power to make them visible. We know also that atoms are the tiny bits of elements that take part in chemical reactions. One grain of sulfur or iron contains many millions of atoms, and it is the atoms of these elements that combine to form iron sulfide. *An atom is the smallest particle of an element that can take part in a chemical reaction.*

Although atoms are exceedingly small, scientists have discovered several methods of finding their weight and size. They have found that an ounce of hydrogen, which is made from the lightest of the atoms, contains about 20,000,000,000,000,000,000,000,000 atoms. It is quite impossible, of course, to comprehend this number, but at least it gives some idea of the exceedingly small size of a single atom. Still another way to think of the size of an atom is to compare the sizes of the earth, a baseball, and an atom. An atom is smaller than a baseball in about the same proportion that a baseball is smaller than the earth.

What are the weights of atoms? The weight of any atom is so microscopically small that the mind is unable to grasp it. The weight of an oxygen atom, for instance, is 0.000,000,000,000,000,000,000,000,1 of an ounce.

For some purposes (you will learn more about this subject in a later chapter) scientists must be able to compare the weights of atoms. Notice the word *compare* because, fortunately, the actual weights of atoms are not particularly important to us. *Relative* weights, however, are very important.

If we compare the weight of an oxygen atom with that of a hydrogen atom we get:

$$\frac{\text{Wt. oxygen atom}}{\text{Wt. hydrogen atom}} = \frac{16}{1}$$

This means that an oxygen atom is 16 times as heavy as a hydrogen atom. Expressed this way, it has some meaning to us.

Scientists have arranged the ninety-eight atoms in the order of their weights by comparing them with the weight of hydrogen (1) or of oxygen (16). These *relative* weights are called the *atomic weights* of the elements. Here are the approximate values of a few of them:

Hydrogen	1	Chlorine	35.5
Helium	4	Iron	56
Carbon	12	Copper	64
Nitrogen	14	Silver	108
Oxygen	16	Mercury	201
Aluminum	27	Lead	207
Sulfur	32	Uranium	238

In general, the atomic weights of the metals are greater than those of the nonmetals.

Molecules. When iron sulfide is formed, one atom of iron combines with one atom of sulfur. What name shall we give to this smallest possible quantity of iron sulfide? Clearly, not an *atom* of iron sulfide. Why not?

The smallest possible group of atoms that form a compound is called a *molecule.* The word *molecule* is derived from the Latin and means "a little heap."

There is another important difference between an atom and a molecule: *a molecule can exist by itself; an atom usually cannot.* If single atoms of oxygen, for instance, are released in a chemical reaction, they cannot remain in the atomic state because they are much too active. Instead, two atoms unite to form a molecule of oxygen. This can be shown in symbols:

$$2O \rightarrow O_2$$

The symbol O stands for an atom of oxygen, the two oxygen atoms are represented by 2O and a molecule of oxygen by O_2, the subscript $_2$ indicating the number of atoms in the molecule. The equation is read "Two atoms of oxygen yield one molecule of oxygen." Hence, *a molecule is the smallest particle of an element or a compound that can exist by itself.*

Study

Structure of an Atom. No one has seen an atom. Scientists have therefore done a great deal of guessing about its structure. Until the end of the 19th century they thought of atoms as minute elastic balls. But this concept could not explain how atoms of different substances unite with one another to form molecules as they do in such compounds as water and carbon dioxide.

For many years scientists thought about the nature of the bonds on the surfaces of atoms. They discovered that some bonds are exceedingly strong, whereas others are comparatively weak. The bonds holding together the atoms in the water or carbon dioxide molecule, for example, are much stronger than those in the sugar molecule. The result is that the bonds of sugar molecules are easily broken by heat, while those of water or carbon dioxide are not. What is the nature of these bonds?

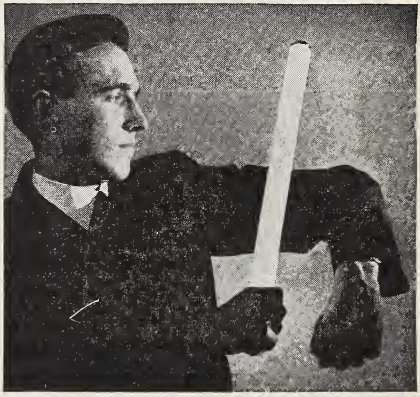


Fig. 3–2. In a dark, dry room on a cold winter night (when the humidity will be especially low), a fluorescent tube will glow if rubbed rapidly on your coat sleeve. Why does the tube glow? *Caution:* Be very careful not to break the tube because the coating inside is dangerous to touch.

(From After Dinner Science *by Kenneth M. Swezey, published by Whittlesey House, New York, 1948. Copyright by the McGraw-Hill Book Company, Inc.)*

The study of electricity shows that *the bonds are electrical.* That electricity is associated with matter can be shown in the following demonstration.

Demonstration 3–3. Electricity by Friction.

Tear some thin paper into small pieces. Rub a glass rod with silk and hold the end of the rod

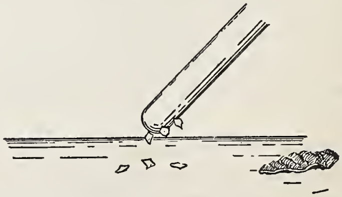


Fig. 3–3. The rubbed glass rod picks up small pieces of paper.

near the paper. Some of the pieces of paper are attracted to the glass rod and stick to it. Pieces of paper are also attracted to a fountain pen rubbed against wool.

The ancient Greeks performed this experiment with a rod of amber instead of glass. The Greek word for amber is *elektron*; it is from this that the word *electricity* is derived.

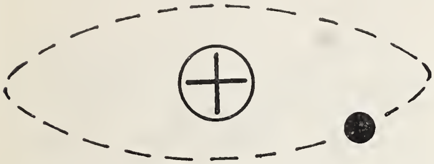


Fig. 3–4. The hydrogen atom has one electron outside the nucleus.

Both amber and glass can be charged with electricity by friction.

Where does the electricity come from? Actually electric charges are present in all matter, and some of these charges can be rubbed off the atoms. The charges that are rubbed off are called *electrons;* they are negative charges of electricity. Electrons can be removed from some substances very easily. Merely scuffing the carpet with our shoes in dry weather is enough to dislodge electrons which accumulate on the surface of our body. If we touch a metal doorknob, the electrons are conducted rapidly away from us, giving us a slight shock.

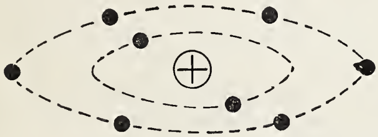
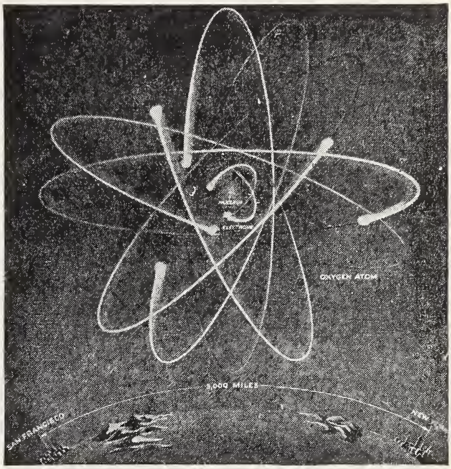


Fig. 3–5. The oxygen atom has eight electrons outside the nucleus.

An atom consists of two parts: negative outside electrons and a positive nucleus, or core. The negative electrons neutralize the positive nucleus and make the atom electrically neutral. Electrons are exceedingly small; the weight of an electron is about $\frac{1}{1800}$ part of the weight of a hydrogen atom. When glass is rubbed with silk, some electrons are torn away from the atoms that make up the glass; as a result the glass is left positively charged. Thus it is able to attract pieces of paper.

Fig. 3–5 shows the oxygen atom, including the paths of the eight electrons, and the large amount of empty space inside the atom. We shall get a good idea of this empty space if we imagine the tiny nucleus of the oxygen atom to be enlarged until its diameter measures 500 yards, which is a little more than a quarter of a mile. In such a case, the diameter of the path of the outer electrons would equal the distance from New York to San Francisco. The electrons would, of course, be only a few yards in diameter, and the rest of the space would be empty.



Courtesy Life *magazine*

Fig. 3–6. If the nucleus of the oxygen atom were 500 yards in diameter, the diameter of the path of the outer electrons would be 3,000 miles.

This picture of the atom is quite different from the elastic-ball theory of a century ago. It is true that atoms are the building blocks of matter, but they are not the smallest particles known to scientists. The smallest known particles are the electrons.

The nucleus of the atom plays no part in chemical reactions. Reactions are due only to the outer electrons. But the nucleus can be split, and the splitting is accompanied by great violence, as was shown by the atomic bomb explosions in World War II. You will learn more about the nucleus in Chapter 57.

THINGS TO REMEMBER

An *element* is a substance that cannot be decomposed by chemical treatment.

A *compound* is formed when elements are linked together.

An *atom* is the smallest particle of an element that can take part in a chemical reaction.

Atomic weights are the relative weights of atoms expressed in terms of the hydrogen atom as 1 or the oxygen atom as 16.

A *molecule* is the smallest particle of an element or compound that can exist by itself.

An *atom* is composed of a central core, or *nucleus*, surrounded by electrons.

An *electron* is a negative charge of electricity.

QUESTIONS

A

1. Define the following: (*a*) element; (*b*) atom; (*c*) molecule.

2. Arrange the following elements in the order of their atomic weights: carbon, uranium, oxygen, hydrogen, nitrogen.

3. Suppose there are a hundred different substances in the laboratory.
(*a*) Could they all be elements? Why?
(*b*) Could they all be compounds? Why?

4. Have chemists ever obtained an atom of water? Explain.

5. The atomic weight of sulfur is 32. What does this mean?

B

6. Suppose you are given two powders, one of which is a mixture of iron and sulfur and the other is iron sulfide. How could you tell one from the other by at least two tests?

7. Describe an experiment you would perform to prove that ordinary matter contains electric charges.

8. What is (*a*) an electron? (*b*) an atomic nucleus?

9. Arrange the following in decreasing order of size: atom, molecule, electron, nucleus.

PROJECT

To Separate the Ingredients of a Mixture of Iron and Sulfur. Thoroughly mix some powdered iron and powdered sulfur. Spread the mixture over a piece of paper and hold one pole of a magnet just above the mixture. The iron is attracted to the magnet and most of the sulfur remains on the paper. Notice, however, that the iron on the magnet has carried some sulfur with it. To remove the sulfur from the iron we must use a liquid that will dissolve the sulfur but not the iron. Such a liquid is carbon bisulfide. *Caution*: Carbon bisulfide is poisonous. Do not get the liquid on your hands or inhale its vapor.

Pick the iron particles off the magnet and drop them into a test tube. Pour some carbon bisulfide into the test tube, about an inch deep. Close the test tube with a stopper and shake the tube thoroughly.

Fold some thin blotting paper or filter paper so that it will hold a liquid. Pour the contents of the test tube into the blotting paper and catch in a dish the carbon bisulfide that passes through it.

Allow the blotting paper to dry. Notice that clean iron remains. The carbon bisulfide in the dish evaporates after five or ten minutes, leaving behind the yellow sulfur.

Can you explain how you could separate a mixture of powdered coal and salt?

Chapter 4

MOLECULES IN MOTION

In Chapter 3 you learned that there are spaces between the molecules of every substance. If there were no spaces between the molecules of water, for example, there would be no room for dissolved particles, and solutions could not be formed.

Solutions. What are solutions? Why are they so important? The first question we can answer at once; the answer to the second will follow a little later. *A solution is a mixture of the dissolving liquid and the dissolved substance.* The liquid is known as the *solvent* and the dissolved substance as the solute. Thus *a solution is a mixture of solute and solvent.* For our purposes the solvent will usually be water. There are other solvents; for example, the tincture of iodine you buy at the drug store is a solution of iodine in alcohol. However, water is by far the most important solvent. The solute may be a liquid, a solid, or a gas; solid and gaseous solutes are more common than liquid solutes. A liquid solute forms a liquid-liquid solution. One interesting example of a liquid-liquid solution suggests, in a convincing way, that there must be holes in liquids.

Demonstration 4–1. To Show There Are Holes in Liquids.

Carefully measure 50 cc. of alcohol and 50 cc. of water. You might estimate that the total volume obtained by adding the alcohol to the water will be 100 cc. But, by pouring the two liquids into a 100-cc. graduate you will actually see that the total volume is about 95 cc.

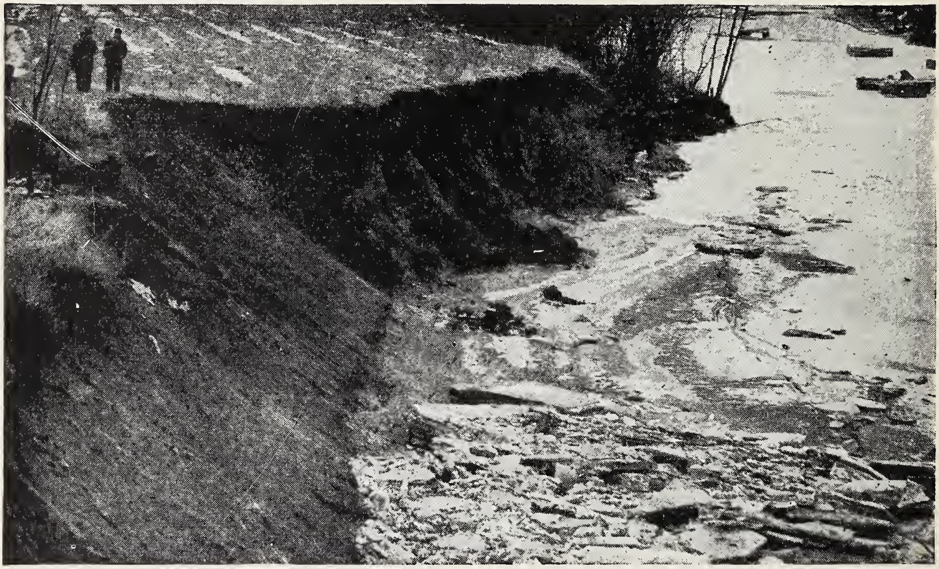
If you remember that there are holes in liquids, you might argue that some of the alcohol molecules will enter the spaces between the water molecules, and, on the other hand, some of the water molecules will enter the spaces between the alcohol molecules. Thus, you account for the fact that the total volume is less than 100 cc.

Fig. 4–1. Reading a graduate.

Solutions of Solids and Their Uses. If solids did not dissolve in liquids to form solutions, there would be no life on the earth—neither plant life nor animal life. Animals must eat to live. The mere eating of food, however, will not sustain life. The food must first be digested; that is, it must be broken down to simpler substances that can be used by the cells of the body. But even the digestion of food is not enough, for the substances that result from digestion pass into the bloodstream. In the blood they dissolve and are carried in solution to all parts of the body to be used to build or repair living tissue.

Solutions also have other uses. The chemist uses solutions of substances to carry out many chemical operations. Let us take, for example, the manufacture of caffeine for use as a stimulant and as an ingredient of some headache powders. Caffeine occurs in nature in tea leaves and coffee beans, and the chemist must extract it from these natural sources. Caffeine does not dissolve in water, but does dissolve in alcohol or chloroform. To extract the caffeine, therefore, tea leaves are boiled with alcohol or chloroform. The solution is then poured off from the fibrous residue and heated. The solvent evaporates, leaving behind the white solid caffeine.

Then there is the great dissolving process in nature. Practically every kind of rock has some soluble constituent. As rivers flow over the land, part of the soil or rock is taken into solution and carried into the sea. In other words, the sea is a solution; and the taste of sea water is due to the substances dissolved in it. Rocks and soils are, of course, only slightly soluble; otherwise they would be rapidly removed from the earth's surface. Nevertheless, the slow dissolving action of river water aids in the important geological process of erosion, which is discussed in Chapter 10.



Courtesy U.S. Soil Conservation Service

Fig. 4–2. The dissolving and eroding action of river water causes wearing of the banks.

It is easy to show the solubility of solids in the laboratory. Potassium nitrate, a white solid, has been selected for this purpose. It is a good plant fertilizer because it dissolves in the water of the soil and is then absorbed by the roots of plants.

Demonstration 4–2. The Solubility of Potassium Nitrate.

Grind some potassium nitrate to a powder. Half fill a test tube with water, add a little potassium nitrate, and shake the tube. The potassium nitrate dissolves. Continue to add the powder until, after shaking, some of it remains undissolved in the tube. When the water has dissolved as much as it can dissolve at that particular temperature, the solution is said to be *saturated*.

Now heat the test tube, and the solid dissolves. Add more powder and continue to heat. A surprisingly large amount of solid dissolves at the higher temperature.

Finally, let the cold water from the faucet run over the outside of the test tube. Since all the solid cannot now remain in solution at the lower temperature, some of it falls to the bottom of the tube as a shower of small crystals.

It is obvious from this experiment that the amount of solid that dissolves depends on the temperature of the water, and that usually *the hotter the water, the greater the amount of solid that it will dissolve*.

The solubility of substances varies considerably. Not all substances are as soluble as potassium nitrate. Chalk, for instance, is almost *insoluble* in water. Can you think of an experiment by which you could show that chalk is insoluble?

Solutions of Gases. Gases dissolve in water just as solids do. Some gases are much more soluble than others. Ammonia is one of the most soluble gases. Its solubility can be shown in the following spectacular demonstration.

Demonstration 4–3. The Solubility of Ammonia.

Pour from 10 to 15 cc. of concentrated ammonium hydroxide into a liter flask. Heat the flask. Ammonia gas escapes from the solution and displaces the air in the flask. Insert in the neck of the flask a stopper fitted with a long tube and a jet that reaches almost to the bottom of the flask. Invert the flask and place the end of the outlet tube well below the surface of water in a jar, as shown in Fig. 4–3. If a few drops of phenolphthalein are added to the water in the jar, the solution that collects in the flask will turn red and will therefore be easier to see.

The ammonia at once begins to dissolve in the water, and more water rises in the tube to fill the space left by the gas. On reaching the top of the tube the water emerges in a fountain, showing that ammonia gas is very soluble in water.

Carbon dioxide is another gas that dissolves in water, although it is much less soluble than ammonia. Carbon dioxide is formed in the cells of the body and passes through the cell walls into the bloodstream, in which it is carried in solution to the lungs. It passes through the membrane of the lungs and finally escapes into the air.

We can readily test for carbon dioxide in exhaled air by breathing into a test tube that contains about an inch of lime water. If the tube is shaken, the solution becomes milky. The only gas that turns limewater milky is carbon dioxide.

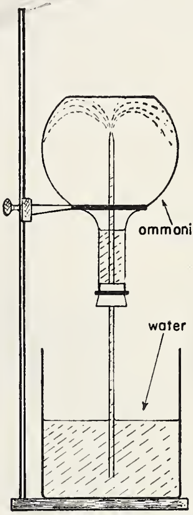


Fig. 4–3. The ammonia fountain.

We can greatly increase the solubility of carbon dioxide by forcing it to dissolve under pressure. The solution formed in this way is called soda water, which is used as a beverage. The bubbles that escape from a bottle of soda water as soon as the cap is removed are carbon dioxide. Much of the gas remains in solution, however, as we can easily prove.

Demonstration 4–4. To Collect Carbon Dioxide from Soda Water.

Pour some soda water into a flask. Support the flask on a stand at a suitable height for heating. Attach a stopper and long tube to the flask as shown in Fig. 4–4. Allow the tube to dip into a vessel in which water and a small shelf have been placed, the shelf being covered by water. Completely fill a bottle with water and then place a glass plate over the top of it. Invert the bottle (placing the mouth of it under water), remove the glass plate, and let the bottle rest on the shelf. Now insert the end of the tube under the bottle.

Heat the flask gently with a small flame. Notice that bubbles of gas rise in the bottle and displace the water.

To prove that the gas is carbon dioxide, turn the bottle upright on the shelf, pour in a little limewater, close the bottle, and shake it. Observe that the limewater becomes milky.

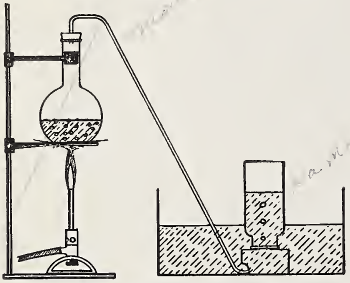


Fig. 4–4. Carbon dioxide escapes when soda water is heated.

This is rather a long experiment, but it illustrates two important points. In the first place, it shows how a gas is usually collected. The air is first removed from a bottle by filling it with water; then the water is removed from the bottle by filling it with gas. Do you think it necessary to fill the bottle with water? Or, in other words, could you get a pure gas into a bottle without using water?

The second thing to observe is that *a gas is less soluble in hot water than in cold water.* That is, in order to drive a gas out of solution we must heat the solution. It is important to remember this, particularly since a solid behaves in the opposite way.

Oxygen is even less soluble in water than carbon dioxide. A small fraction of the oxygen of the air dissolves in water. This oxygen is essential to the respiration of fish. As the water passes through their gills, some of the dissolved air is removed from the solution and in this way the fish obtain the oxygen they need to live.

Spaces in Gases. We have already stated that solutions are formed when the molecules of the solute occupy the spaces between the molecules of the solvent. In this way are formed solid-liquid solutions, liquid-liquid solutions, and gas-liquid solutions. It is also possible to make solid-solid solutions, as in steel alloys.

But what about solutions of gas in gas? Earlier in the chapter we said that water is the most important solvent. Is air also a solvent? We live in an ocean of air, and so we are vitally concerned with it. Actually, scientists do not usually speak of "air solutions" because the holes in air—or in any gas—are much larger than those in water; as a result, the air spaces are much easier to penetrate. The pleasant aroma of percolating coffee spreads through the house. This is because some molecules of the coffee escaped into the air and traveled many yards, eventually reaching our noses.

In a gas the molecules are relatively far apart. If we could magnify one cubic inch of air about one hundred million (100,000,000) times, the air molecules would look like mosquitoes in a space the size of a large theater. The "mosquitoes" would be darting about at high speeds. The average distance between them would be about ten feet. This picture brings out the important fact that *a gas is almost empty space.*

It should now be obvious why a gas is so easily compressed. When we compress air, as in a bicycle pump, we do not change the size of the molecules, but merely reduce the empty spaces between them.

Motion of Gas Molecules. Since there are large spaces between the molecules of a gas, the molecules can move without getting very much in one another's way. The molecules of liquids and solids can also move, but they are more crowded and thus interfere with one another's motion. Indeed, *all molecules are always in a state of motion, and the hotter a substance becomes the faster they move.*

The effects of moving gas molecules can be shown by experiment. The gases we select for this purpose are air and hydrogen: air because it is easily available, hydrogen because it is the lightest gas. (As we might expect, *the lighter the gas, the faster it will move.*) The hydrogen will spread into the air and the air into the hydrogen. This process is called *diffusion.*

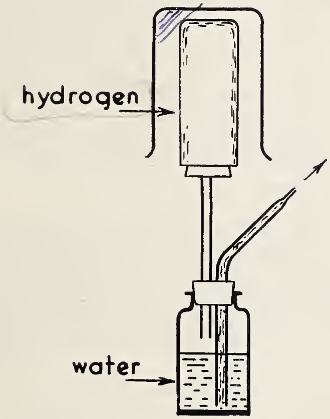


Fig. 4–5. A stream of water escapes through the nozzle when hydrogen diffuses through the porous cup.

Demonstration 4–5. Diffusion of Hydrogen into Air.

Arrange the apparatus as shown in Fig. 4–5. It consists of a bottle half filled with water. The stopper of the bottle holds two outlet tubes. One tube dips into the water and ends in a jet, and the other is attached by a stopper to a porous earthenware cup. Now place a large inverted beaker or battery jar containing hydrogen* over the porous cup. Almost instantly a stream of water is forced out of the jet of the outlet tube.

What forces the water out of the tube? The only force capable of doing this is the force exerted on the surface of the water in the bottle. But how has the force on the water surface been suddenly increased? This extra force or pressure is caused by the hydrogen molecules which diffuse through the pores of the cup and pass into the space above the water surface. The high-speed hydrogen molecules bombard the water surface and force some of the water out of the bottle. The gas pressure caused by moving hydrogen molecules is considerable; it is probably greater than the pressure you can exert with your lungs. If you wish to compete with the hydrogen, first remove the porous cup and stopper from the end of the tube and then blow as hard as you can down the tube. You can force some water out of the bottle, but can you exert as much pressure as the moving hydrogen molecules?

What about the motion of the air molecules? Some air molecules undoubtedly pass out through the wall of the porous cup, but the apparatus is not designed to indicate the motion of air molecules. However, we can be sure that the speed of the air molecules *out* is much less than the speed of the hydrogen molecules *in,* for otherwise there would not be an increase in pressure. In other words, *the lighter hydrogen molecules move faster than the heavier air molecules.*

We must not think that diffusion is limited to gases; it occurs in liquids and even in solids. The diffusion in liquids—that is, the motion of dissolved particles in solution—is, of course, much slower than in gases. It plays an important part in the digestion of food.

Motions of Molecules of Liquids and Solids. Thus far we have said little about the motions of molecules in liquids and solids. In a liquid the molecules are closer together than they are in a gas. Nevertheless, they can move easily, and a liquid can therefore assume the shape of the vessel it occupies. Some of the molecules near the surface may even escape from the liquid into space. This process is called *evaporation.* Probably you have seen many instances of evaporation—the drying of your body after bathing, the gradual disappearance of water exposed to the air, the drying of roads after a summer rain.

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* Hydrogen can be obtained most conveniently from a small cylinder suitable for classroom demonstrations. If a cylinder is not available, the gas can be prepared by the method described in Chapter 23.

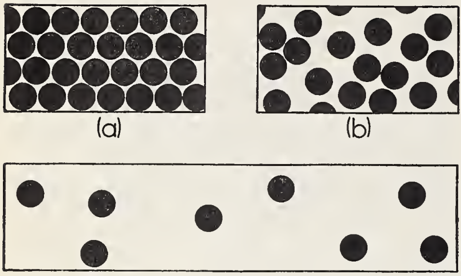


Fig. 4–6. The regular, close packing of the molecules of a solid (*a*); the irregular arrangement of the molecules of a liquid (*b*); and the irregular and open arrangement of the molecules of a gas (c).

The movement of molecules in solids is different from that of molecules in liquids and gases. In a solid, the molecules are so close together that they attract one another with a strong force that holds them in a fixed shape or pattern. *The only way the molecules of a solid can move and still retain their pattern is by vibrating back and forth.* If a solid is heated, the speed of vibration steadily increases until, eventually, the molecules break away from one another. The pattern is then broken, the molecules move about freely, and we say the solid has melted.

Solid glass can easily be melted by heat. Before it melts completely, it passes through a plastic stage in which the glass is soft and can be molded or blown to form such things as beakers, flasks, and bottles.

Demonstration 4–6. To Soften Glass by Heat.

Hold a piece of glass tubing about 9 inches long in a Bunsen flame. When the tube is soft, remove it from the flame and stretch it into a long, fine capillary tube. (*Capillary* is derived from a Latin word meaning "hair.")

When the glass is removed from the flame, the air cools it, the molecular motion slows down, and the molecules again become fixed and form a pattern.

Fig. 4–6 shows roughly the spacing of the molecules in solids, liquids, and gases. The solid molecules show a regular pattern; the liquid molecules show irregular spacing; the gas molecules have large spaces between them.

THINGS TO REMEMBER

A solution is a mixture of solute and solvent.

A solution is *saturated* if it contains the maximum amount of solute it can hold at a particular temperature.

The *solubility of a solid* is usually increased as the temperature is raised.

The *solubility of a gas* is decreased as the temperature is raised.

Gas molecules are in a state of *rapid motion:* the higher the temperature, the faster the motion; the lower the temperature, the slower the motion.

Diffusion is the mixing of different molecules and is caused by their motions.

Light gases diffuse *rapidly*; heavy gases diffuse more *slowly*.

Gas pressure is caused by the molecular bombardment of a surface.

Evaporation is the escape of liquid molecules into the space above the liquid.

The *molecules of a solid* are held by mutual attraction in a fixed pattern.

QUESTIONS

A

1. Determine which of the following statements are true and which are false. Then correctly reword the false ones.

(*a*) A solution may be a mixture of any solid and water.

(*b*) A saturated solution of a solid is made less saturated by heating it.

(*c*) Ammonia is a more soluble gas than oxygen.
(*d*) Carbon dioxide molecules diffuse faster than hydrogen molecules.
(*e*) If their temperature is raised, carbon dioxide molecules can be made to travel as fast as hydrogen molecules.
(*f*) Oxygen is more soluble in cold water than in hot.

2. What is: (*a*) a solution; (*b*) a saturated solution?

3. Suppose a saturated sugar solution is cooled. What happens? Why?

4. Give an example of: (*a*) a solution of a solid in a liquid; (*b*) a solution of a liquid in a liquid; (*c*) a solution of a gas in a liquid.

5. How can you prove that exhaled breath contains carbon dioxide?

6. How would you prepare a saturated solution of sugar?

7. In what ways are solutions important?

8. (*a*) What is meant by diffusion?
(*b*) Draw and label a diagram of the diffusion experiment.

B

9. How could you get pure dry salt from a mixture of salt and chalk?

10. Suppose goldfish are placed in cold water that has been recently boiled. What happens? Why?

11. Draw and label a diagram to show how you would collect a bottle of exhaled air by displacing water.

12. You are given (1) a saturated solution of potassium nitrate and (2) a saturated solution of carbon dioxide. How could you get *more* potassium nitrate in solution (1) and *less* carbon dioxide in solution (2)? Give reasons for the steps you would take.

13. (*a*) What causes gas pressure?
(*b*) If a gas is heated, does the pressure increase or decrease? Why?

14. How can you prove that large spaces exist between the molecules of a gas?

15. A water solution is saturated with air and sugar. If the solution is heated, what happens to: (*a*) the solution; (*b*) the air; (*c*) the sugar?

PROJECTS

1. *To Show the Solubility of Air in Water.* Pour tap water into a beaker until it is about three-quarters full. Place the beaker on a stand and heat it with a Bunsen burner. Notice the escape of air bubbles long before the water boils.

Why does the dissolved air escape when the water is heated?

Would you expect to find more lively fish in cold mountain lakes or in tropical water? Why?

2. *Testing the Solubility of Rock.* We usually think of limestone and chalk as insoluble rocks. Are they really insoluble? To find out, place a little finely powdered chalk in a clean test tube. (In chemistry and geology, chalk means calcium carbonate, not blackboard chalk.) Half fill the test tube with water. Close the tube with a well-fitting stopper and shake it thoroughly for several minutes. Then allow the contents to settle for about ten minutes.

Now pour a little of the water through a filter paper and catch the filtered water in a watch glass or evaporating dish. Put the dish aside for a day or so until the water has completely evaporated. Notice the faint white residue in the dish. What is the residue? Where has it come from? Does the residue prove that chalk is slightly soluble? What modification in the experiment would you suggest to increase the residue? Why not try it?

heating a gas makes it less soluble

Chapter 5

AIR, AN IMPORTANT MIXTURE

Like many gases, air is a substance we cannot see. How, then, do we know it is a substance or material? There is plenty of evidence that air is material just as a liquid or a solid is. Air can turn the arms of a windmill; it can drive a sailing ship across the sea; it can buoy up airplanes and birds. If the wings of a bird could not push on the air, the bird would not be able to fly. The air must therefore be a substance.

How far does the air extend beyond the surface of the earth? There is no exact answer to this question. We know that the air gets thinner and thinner with higher and higher altitudes, and we have a fairly good idea of the extent of the atmosphere from the way meteors behave. Meteors are not shooting stars; indeed they are not stars at all. Usually they are specks of dust that have been in outer space and have come near enough to the earth to be attracted by it. They approach the earth at high speeds, often as high as 25 miles a second, or 90,000 miles an hour. Higher than 100 miles above the earth there is not air enough to cause a meteor to shine. But at a height of about 80 miles from the earth's surface meteors encounter denser air. Since they travel at very high speeds, the atmospheric friction causes them to become white-hot and burn up. The heights of these meteors can be calculated. It is found that on the average they are only between 40 and 80 miles above the earth's surface. Of course, the atmosphere extends beyond the meteor region, probably by several hundred miles; but it is so thin in these high altitudes as to be almost a vacuum. The atmosphere is a huge ocean of air that is most compact at the bottom, and it is at the bottom of this mighty ocean that we spend our lives.

Why does the air remain with the earth? Why does it not escape into space? Though the air is very light and though the earth travels around the sun at an enormous speed, the air stays with the earth. Why? Actually the earth travels round the sun in 365¼ days. To make this long journey it must travel 18½ miles per second, or nearly 70,000 miles an hour. It might seem that the earth would leave the air behind, somewhere in space. But the same attractive force that pulls meteors toward the earth is exerted on the molecules of air, with the result that the atmosphere is held in place. We know that some of the planets have lost their atmosphere. The moon has no atmosphere. It is a much smaller body than the earth and therefore exerts a much smaller attractive force than the earth. This force is not large enough to hold air molecules near its surface. Even if the moon had originally had an atmosphere, it could not have retained it.

Air Has Weight. Compared with water, air does not weigh very much. The air in a box 3 feet long, 2 feet wide, and 2 feet deep weighs only 1 pound; the air in a room 30 feet by 20 feet by 10 feet weighs about 500 pounds; but the weight of the whole atmosphere is almost 4,000,000,000,000,000 tons. By the following experiment we can easily show that air has weight.

Demonstration 5–1. To Show That Air Has Weight.

Place a short glass tube through a one-hole stopper and fit the stopper into a large round-bottom flask. Connect the glass tube to an aspirator or airpump by means of heavy-walled rubber tubing with a pinch clamp attached. Turn on the faucet so as to remove air from the flask. After a minute or two tighten the pinch clamp and disconnect the rubber tube from the aspirator. Place the flask on a balance and counterpoise it with weights. Now release the pinch clamp. Air rushes into the flask, and the balance registers a marked increase in weight.

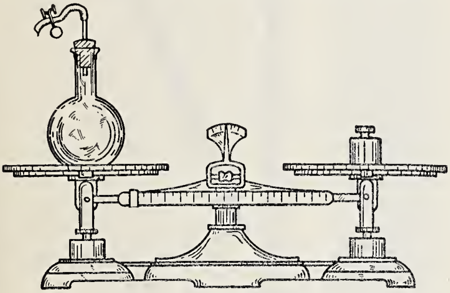


Fig. 5–1. Air has weight.

Air Pressure. Since air has weight, it exerts a pressure on the surfaces on which it rests. We can demonstrate that the pressure of the air is considerable.

Demonstration 5–2. To Show That Air Exerts a Pressure.

Place a piece of glass tubing through a one-hole stopper and fit the stopper into the outlet of a tin can. (A can about 15″ x 12″ x 9″ is satisfactory for this purpose.) Attach the glass tube to an aspirator and turn on the faucet. In a few minutes the sides of the can begin to buckle, and eventually the can collapses, as shown in Fig. 5–2.

What caused the can to collapse? It is reasonable to suppose that the cause is the *inward* pressure of the air. Then why didn't the can collapse before the air was withdrawn? Originally there was air inside the can, and, since air pressure is exerted in all directions, the air inside exerted an *outward* pressure which balanced the *inward* pressure. The balancing of pressures in the open vessel is shown in Fig. 5–3. As the air was removed the pressure inside diminished. As a result the pressure of the atmosphere exceeded the pressure inside the can and was able to crush it.

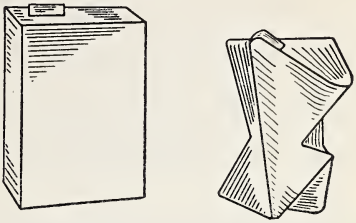


Fig. 5–2. A gallon can crushed by atmospheric pressure.

Measuring Air Pressure. Everything on the earth is affected by air pressure; nothing can escape it, except when a special device is designed to control it. Engineers, physicists, chemists, meteorologists, geologists are all interested in the *amount* of pressure exerted by the air. Air pressure can be measured in several ways. Probably the simplest way is to

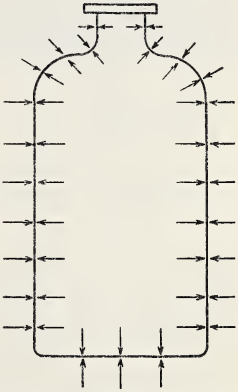


Fig. 5–3. The pressure inside a bottle is the same as the pressure outside.

balance a column of air extending from the surface of the earth to the limit of the atmosphere (a distance of several hundred miles) against a column of liquid as shown in Fig. 5–4. If the balancing liquid is water, the water column is 34 feet high. We can say, therefore, that *the pressure of the atmosphere is balanced by the pressure of a 34-foot column of water*. But a column of water of this length cannot conveniently fit into a measuring instrument. By using a liquid that is heavier than water, we can make the liquid column shorter. Mercury is 13.6 times as heavy as water; therefore, a column of mercury will be only one-fourteenth as high as a column of water. By calculation we would expect the mercury column to be $\frac{34}{13.6}$, or 2.5 feet, or 30 inches. We can check this result experimentally by an instrument known as a *mercury barometer*.

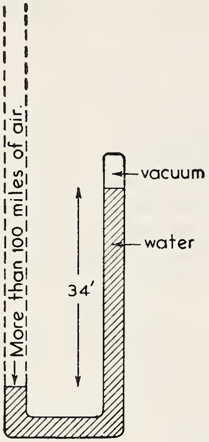


Fig. 5–4. A water column 34 feet tall balances an air column which extends to the limits of the atmosphere.

Demonstration 5–3. To Make a Mercury Barometer.

Take a barometer tube (which is a glass tube sealed at one end and about one yard long and half an inch in diameter) and fill it with mercury. Close the open end with the finger, invert the tube, and place the open end well below the surface of mercury in a bowl or beaker. Now remove the finger.

Notice that the mercury falls at once so that it no longer fills the tube. Measure the height of the mercury column from the surface of the mercury to the top of the column. It will probably be a little more than 29 inches. Tilt the tube as shown in Fig. 5–5.

Notice that the mercury level remains at the same height, 29 or 30 inches above the outside surface. The space above the mercury level is diminished, however, and it may disappear altogether if the tube is sloped sufficiently. This proves that the space contains no air; it is empty. Such a space is known as a *vacuum*.

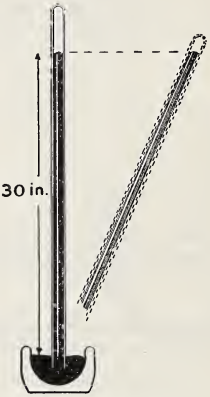


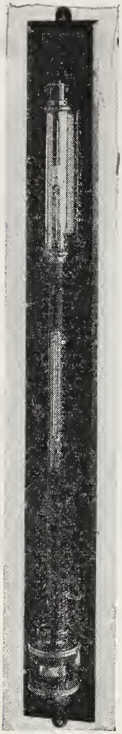
Fig. 5–5. A simple barometer.

The weight of the mercury tries to force the mercury *down* the tube; the weight of the air column exerted on the surface of the mercury in the beaker tries to force mercury *up* the tube. The mercury level remains constant because these two forces balance each other. Hence we can say that *the pressure of the atmosphere is equal to the pressure of a column of mercury about 30 inches tall.* In other words, we usually express air pressure in terms of mercury pressure.

Another way of measuring pressure, and one that we shall frequently use in this book, is to calculate the pressure exerted on every square inch of surface. If the area (that is, the area of a cross-sectional surface) of the barometer tube happened to be 1 square inch and the height of the column 30 inches, the total weight of the mercury in the tube would be nearly 15 pounds. Thus a column of mercury 30 inches tall exerts a pressure of 15 pounds per square inch; therefore *the pressure of the atmosphere is approximately 15 pounds per square inch.*

The pressure of the air does not, of course, remain constant day after day. For this reason, the height of the mercury column is constantly changing. A rising barometer may indicate fair weather, and a falling barometer may indicate an approaching storm. The relationship between barometric pressure and weather is discussed in Chapter 20.

Air Pressure Changes with Elevation. Since air is easily compressed, it is densest at the earth's surface; it gets progressively thinner as it rises above the surface. At a height of about 3½ miles the pressure of the air is just about half the pressure at the surface. This means that if you take a deep breath at this altitude, only half as much air passes into your lungs as at sea level, and in order to inhale the necessary amount of oxygen, you will have to breathe twice as fast. At still higher altitudes, breathing would become a difficult and tiring operation, until eventually there would not be enough oxygen to support life. That is why aviators traveling at high altitudes wear oxygen masks or fly planes with pressurized cabins.



Courtesy Taylor Instrument Co.

Fig. 5–6. An accurate barometer.

Mountain climbers know that the air changes as they ascend and that it takes some time to get accustomed to breathing thin air. Mount Everest, in the Himalayas north of India, which is 5½ miles (29,000 feet) above sea level, has thus far defied man's attempts to reach the highest peak on the earth. The medical officer attached to one expedition on Mount Everest reported that difficulty in breathing became noticeable at 14,000 feet. Above 19,000 feet the slightest exertion, even tying a shoestring, caused distress in breathing. At 27,000 feet the climbers had to take eight or nine respirations for each step they made. At 28,000 feet it took about an hour to ascend 80 feet, and the strain at this altitude was so great that it was impossible to proceed further without the use of oxygen. See Fig. 5–8.

Courtesy R. F. Brinckerhoff

Fig. 5–7. Measuring the atmospheric pressure at the top of Mount Washington (6,290 feet). The barometer, which was assembled at the summit, read 24.2 inches (61.5 cm.). The boiling point of water at this pressure, as measured by the boy at the left, was 91° C. (See page 153.)

On Measuring Things. On some barometers the height of the mercury can be read on two scales, one in inches and the other in centimeters. Inches are units in the British system; centimeters are units in the metric system.

Units of Length. In the British system a given length may be expressed in various units. For instance, a boy's height may be 6 feet, or 2 yards, or 72 inches, or even 0.0013 mile. The distance between New York and Boston is about 200 miles, or 352,000 yards, or 12,672,000 inches. The last figure is so large that it is difficult to imagine. For each case there is one unit that best suits the particular length we are measuring. For example, we say that the boy is 6 feet tall and that the distance between New York and Boston is 200 miles.

Courtesy Mäuser from Official Information Bureau of Switzerland

Fig. 5–8. These mountain climbers have reached an altitude of 10,627 feet above sea level where, in order to get enough oxygen, they must breathe more often because of the reduced air pressure.

Selecting the most convenient unit is important, but we must also be able to convert one unit into another. For this purpose we should know that:

12 inches = 1 foot
3 feet = 1 yard
1760 yards = 1 mile
5280 feet = 1 mile

In science we generally use another system of measurement, the *metric system.* Indeed, this system is commonly used in most countries, the United States and England being the exceptions. The metric system is a decimal system. It is therefore simpler than the British system, which we use for everyday purposes.

The units of length in this system are:

10 millimeters (mm.) = 1 centimeter (cm.)
100 centimeters = 1 meter (m.)
1000 meters = 1 kilometer (km.)

The prefixes *milli-*, *centi-*, and *kilo-* mean, respectively, "one thousandth of," "one hundredth of," and "one thousand times," the standard, which in this case is the meter.

A millimeter is about equal to the thickness of the wire of a paper clip; a centimeter is almost equal to the width of one's index fingernail; a meter is a little longer than a yard.

Since we shall refer to both the British and metric systems in this book, we must be able to change units of one system into units of the other. To do this, we should remember that:

2.54 centimeters = 1 inch
or 1 meter = 39.37 inches

Let us now refer again to the height of the barometer, usually about 30 inches:

$$30 \text{ inches} = 30 \times 2.54 = 76.2 \text{ centimeters}$$

We usually say that the normal pressure of the atmosphere is equal to the pressure exerted by 76 cm. of mercury.

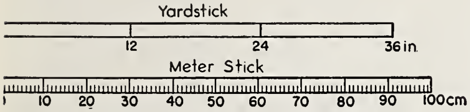


Fig. 5–9. Comparison of the yardstick and meter stick.

Units of Weight. Before leaving the units of measurement, let us return to Demonstration 5–1. It would be reasonable to ask, What is the weight of the air in the flask? To answer this question, we must know what is meant by units of weight.

Ordinary weights are measured in pounds and ounces, and large weights in tons. We know that:

16 ounces (oz.) = 1 pound (lb.)
2000 pounds = 1 ton

In the metric system, weights are expressed in grams and kilograms. The units of weight are:

1000 milligrams (mg.) = 1 gram (g.)
1000 grams = 1 kilogram (kg.)

The milligram is used to measure very small quantities, but the gram and the kilogram are more commonly used. A nickel, for example, weighs 5 grams, a dime 2.5 grams, and a dollar bill 1 gram. A high-school boy may weigh from 60 to 80 kilograms.

Suppose that the flask containing air weighed 97.30 g. and that after the air had been removed it weighed 96.75 g. It follows that the air in the flask weighed 0.55 g. If the volume of the flask is 500 cubic centimeters (cc.), we could say that 1000 cc. of air weighs 1.10 g.

The important conversion factors (or equivalents) in the two systems of weight are:

2.20 pounds = 1 kilogram
454 grams = 1 pound

The weight of a substance can therefore be expressed in either unit. Indeed, you may have noticed that some packages, especially those containing medicines, have the weight indicated in both the metric and the British systems.

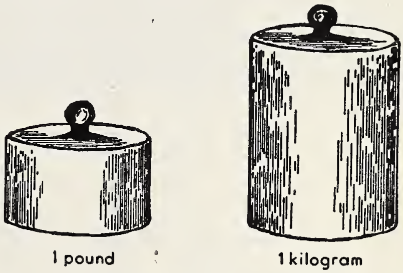


Fig. 5–10. Comparison of the pound and kilogram.

Let us now return to our discussion of air.

Air Is a Mixture. We have already discussed molecules of air. Exactly what are molecules of air? What is air made of? Air is a *mixture* of gases, chiefly oxygen and nitrogen. In air, oxygen is free; it is not bound to the nitrogen. In the compound water, oxygen is not free; it is bound to the hydrogen.

Electricity is needed to break the bonds between the hydrogen and oxygen atoms in water; but since there are no bonds to break in the case of air, the separation of oxygen and nitrogen is much simpler. This is done by cooling the air until it becomes liquid. The liquid is then warmed slightly so that the nitrogen is boiled away, leaving behind liquid oxygen. This is a common method of separating the constituents (parts) of a mixture. For example, the constituents of petroleum, such as gasoline and kerosene, are simply boiled off at different temperatures (see Chapter 26).

Chemical Reactions with the Oxygen of the Air. *Oxygen is a chemically active element* and takes part in many reactions. Indeed, the reactions of burning, and the life processes themselves, could not take place without oxygen. The red rust of iron is formed when iron reacts with the oxygen of the air.

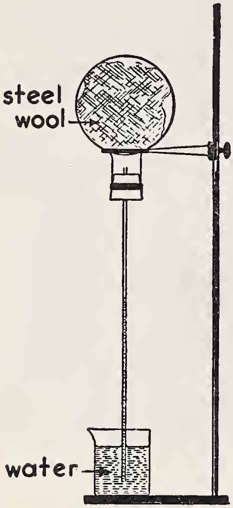


Fig. 5–11. The rusting of iron.

Demonstration 5–4. The Rusting of Iron.

Place some moist steel wool (steel wool is about 90% iron) in a flask. Close the flask with a stopper in which a piece of glass tubing at least a foot long has been inserted. Invert the flask and support it so that the lower end of the tube is below the surface of colored water in a beaker. The arrangement is shown in Fig. 5–11.

Notice that, as the iron in the steel wool rusts, the water rises slowly in the tube and continues to do so for several hours. Eventually it stops rising. *Note:* Rusting will take place much faster if the steel wool is dipped into dilute acetic acid before it is put into the flask.

This demonstration should be observed carefully because we shall refer to it in later discussions. Why does the water rise in the tube? What happens to the oxygen in the flask? Why does the water stop rising?

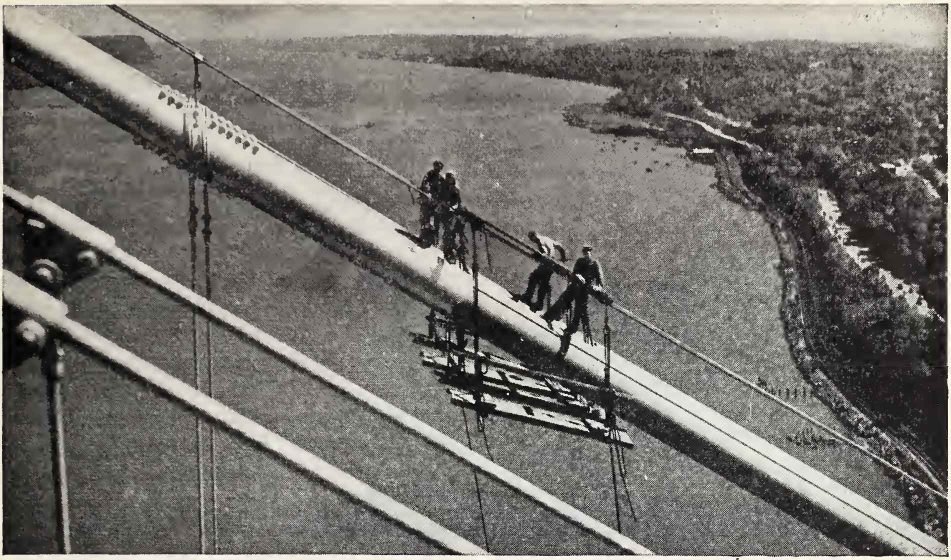
The oxygen combines with the iron to form a solid which we call iron oxide or rust:

iron + oxygen → iron oxide

Since iron oxide is a solid, the volume of gas in the flask is diminished and water rises in the tube to replace the oxygen. When all the oxygen has been used up, the water stops rising. In other words, the volume of the water that has risen into the tube and flask is a measure of the volume of the oxygen that was originally present in the air in the flask. If we measure this water in a graduate, we find that it equals about one-fifth the volume of the air originally in the flask. And so we conclude that *about one-fifth, or 20 percent, of air is oxygen.*

The rusting of iron or steel is a serious problem. Steel is the basis of modern construction; bridges, skyscrapers, and automobiles are made largely of steel. If steel were allowed to rust, a structure would weaken and eventually collapse. The only way to prevent rusting is to protect the steel from the oxygen in the air. This is usually done by painting it. You may have noticed that when steel girders are delivered from the factory, they already have a protective coat of red paint, called red lead. When the construction is completed, a second coat of paint, usually of a softer color such as gray, is added to give further protection to the steel.

Nitrogen. What remains in the air after the oxygen is removed? The gas is nitrogen. What are the chemical properties of nitrogen?



Courtesy Port of New York Authority

Fig. 5–12. The surface of the steel bridge is being painted to prevent rusting from the oxygen in the air.

How do they compare with those of oxygen?

Before answering these questions, let us prepare a sample of nitrogen, again by removing oxygen from the air. This time, however, we shall burn the element phosphorus to remove the air. Yellow phosphorus is poisonous and inflammable; it should never be touched with the hands and it should always be kept under water when not in use.

Demonstration 5–5. The Preparation of Nitrogen.

Place a small block of wood in a trough containing a little water. With forceps remove a piece of phosphorus from the bottle and cut off a piece about the size of a small pea. Replace the larger piece of phosphorus in the bottle. Dry the small piece of phosphorus on a filter paper and place it on the wood. Touch the phosphorus with the end of a hot wire and as soon as it begins to burn invert a tall beaker over the phosphorus and hold it there.

The phosphorus burns vigorously for a few seconds, then the flame goes out. Notice that a white powder, which eventually dissolves in the water, is formed. As the gas cools, the water rises in the beaker. Observe the height of the water in the beaker and calculate roughly the fraction of air that remains.

The white powder is phosphorus rust, or phosphorus oxide. What has happened to the

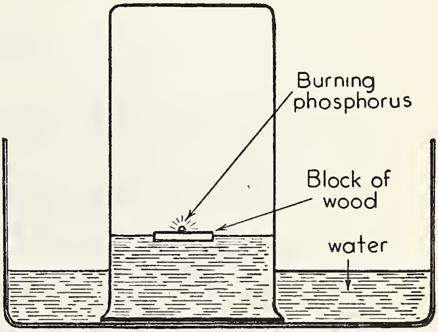


Fig. 5–13. Burning of phosphorus. Why is the water level higher in the beaker than in the trough?

oxygen? The remaining gas is nitrogen, and a simple calculation shows that it occupies about four-fifths, or 80 percent, of air.

What is the marked difference between the chemical properties of oxygen and those of nitrogen? Oxygen is the *active* part of the air; that is, it readily takes part in chemical reactions. Nitrogen is the *inactive* part of the air; it does not readily take part in chemical reactions.

Composition of Air by Volume. When air is analyzed it is found to consist of other substances besides oxygen and nitrogen, but these substances are present only in small amounts. The composition of dry air, by volume, is approximately:

	Percent
Nitrogen	78.0
Oxygen	21.0
Argon	0.94
Carbon dioxide	0.04
Other gases	0.02

That is, oxygen and nitrogen together make up 99 percent of the air. The gas argon, which constitutes about 1 percent, is chemically inactive, and it is relatively unimportant. The carbon dioxide, however, which is only 4 parts in 10,000 parts of air, is necessary to the natural processes upon which life depends. Here, then, is a puzzling question: How can both plant and animal life be so dependent upon a gas that is present in so small a quantity? This question will be discussed in Chapter 29.

THINGS TO REMEMBER

The *atmosphere* is held to the earth by a force of attraction.

Atmospheric pressure is equivalent to the pressure of about 30 inches or 76 centimeters of mercury, or about 15 pounds per square inch.

Atmospheric pressure *decreases* as the distance above sea level *increases*.

The *composition* of dry air is:

	Percent
Nitrogen	78.0
Oxygen	21.0
Argon and other gases	1.0

Oxygen is an *active* element; nitrogen is an *inactive* element.

Metric Units of Length

10 mm. = 1 cm.
100 cm. = 1 m.
1000 m. = 1 km.

Metric Units of Weight

1000 mg. = 1 g.
1000 g. = 1 kg.

Conversion Factors

2.54 cm. = 1 in.
1 m. = 39.37 in.
2.20 lb. = 1 kg.
454 g. = 1 lb.

QUESTIONS

A

1. Determine which of the following statements are true and which are false. Then correctly reword the false ones.
   (*a*) The atmosphere extends for a distance of only 40 to 80 miles above the earth.
   (*b*) There is no atmosphere on the moon.
   (*c*) Atmospheric pressure acts only in one direction—downward.
   (*d*) The atmosphere will support a 34-foot column of mercury.
   (*e*) Atmospheric pressure is about 15 pounds per square inch.
   (*f*) A barometer is an instrument that indicates atmospheric pressure.
   (*g*) Air is a mixture of approximately 80 percent nitrogen and 20 percent oxygen.
   (*h*) Oxygen is more active chemically than nitrogen.

2. Explain why the water in the inverted bottle shown in Fig. 5–11 does not fall out.

3. What is the reaction between phosphorus and oxygen?

4. Name a compound that contains one of the x 5280

elements: (*a*) iron; (*b*) carbon; (*c*) sulfur; (*d*) hydrogen.

5. State the composition of air.

6. In Demonstration 5–3 the statement is made that the tube does not remain filled with mercury when the finger is removed. Why not?

B

7. What is a meteor? What information do meteors give concerning the atmosphere?

8. Describe an experiment to prove that the air has weight.

9. An empty bottle is opened in a plane that is 2 miles above the earth's surface. The bottle is sealed until the plane makes a landing; then it is opened again.

(*a*) When the plane was 2 miles up, did air enter or leave the bottle? Why?

(*b*) When the plane was back on the ground, did air enter or leave the bottle? Why?

10. The height of the mercury column in barometers having tubes of different diameters is the same. Why is this true?

11. A barometer reads 29 inches. Express this reading in: (*a*) centimeters; (*b*) millimeters.

12. The distance from New York to Boston is 200 miles. What is the distance in kilometers?

13. Find the weight of a 150-pound boy in kilograms.

14. In the iron-rusting experiment suppose that the volume of air originally in the flask and tube was 1,100 cc., and that the volume of water that rose in the tube was 220 cc. From these data calculate the percentage of oxygen in the air.

20%

PROJECTS

1. *To Record Barometric Readings and Weather Conditions.* Make a barometer as explained in Demonstration 5–3. Read the barometer at approximately the same time every day for two or three weeks. Record on a chart: (*a*) the date, (*b*) the barometric reading, and (*c*) the kinds of weather, such as fair, rain, windy, etc.

   At the end of that time, examine the data you have collected. Can you find any relationship between the barometric reading and the weather? For example, is rainy weather associated with a high or a low pressure? Is wind associated with high or low pressure?

2. *To Convert Measurements into Different Units*

   (*a*) Measure the length of this page in inches. Using the conversion factor, calculate its length in centimeters. Check your result by measurement with a ruler marked off in centimeters.

   (*b*) Measure the width of this page in centimeters. Calculate the width in inches, then check your answer by measurement.

2.54
29

1 lb. = 454 grams

Chapter 6

WATER, AN IMPORTANT COMPOUND

If we were asked to name the most important chemical compound, we would naturally turn to the most plentiful one, water. Water is used in enormous quantities in the household and in industry. It is necessary to all forms of life; all plants and animals need it in abundance. Not only do they need it to keep alive, but they are largely made up of water. About 70 percent of a person's weight is water. The body of a man weighing 150 pounds is approximately 105 pounds water. Vegetables have an even larger percentage of water. A potato, for example, is about 78 percent water, an apple about 85 percent, a cabbage about 90 percent, and a watermelon about 98 percent. Some kinds of sea creatures consist of proportionately more water than vegetables do. A jellyfish, for instance, holds nearly 99 percent water. All ordinary foods contain a good deal of water; milk has about 87 percent.

Air contains water in the form of vapor,

Courtesy General Electric Co.

Fig. 6–1. Water from melting snow. With the spring thaws, water flows to the lowlands, producing spectacular falls like these in the Yosemite Valley, California.

although the amount varies considerably in different places. In New York and other cities situated near the sea there is likely to be a great deal of water vapor in the air during the summer. We say the humidity is high. Clouds consist entirely of water in the form of tiny droplets.

Water in Industry. Make a list of half a dozen cities or large towns you are familiar with. Is each of these towns situated on a river? What purposes does each river serve?

It is not easy to think of any sizable town that is not on a river. In fact, most of the sites of our cities were selected because of their nearness to a river. Enormous quantities of running water are required by most industries, such as paper making, sugar refining, dyeing, tanning, soap making, textile manufacture, and all chemical plants need large amounts of it.

In industry water is used as a solvent, for cleansing, for cooling, for hydroelectric power, and to carry away waste. In the selection of a suitable factory site, therefore, some attention must be given to the nature of the water itself. Some rivers, like the Mississippi carry a great deal of sediment, and their waters are *hard;* that is, they contain certain minerals in solution that make it difficult to form a lather with soap. Both sediment and hardness are objectionable in water. The sediment can, of course, be filtered out and the hardness removed by chemicals. But these are expensive processes and, wherever possible, it is an advantage to select water that is soft and contains little sediment.

It is an interesting fact that fleece from Australia is often shipped all the way to the United States, almost halfway round the world, before being washed. Sheep can thrive on land that is too dry for cultivation. From their almost rainless habitat, they gather a great deal of dust in their fleece. When the fleece is sheared, about half of its weight is dirt. The first step in the manufacture of wool is a thorough washing of the fleece. Australia is short of good water supplies, and so the washing takes place at the point of manufacture. This is true also of wool from New Zealand and South America, which is transported thousands of miles before it is washed and prepared for manufacture.

Hard and Soft Water. As stated above, soap does not lather well in hard water; therefore the hardness must be removed chemically. Hardness is caused by compounds of calcium or magnesium in solution. The water in limestone (calcium carbonate) districts, for instance, is usually hard.

When hard water is shaken with soap, a scum or curdy precipitate is formed. In other words, the soap reacts chemically with the compounds, causing hardness. Thus the soap is not free to do its work of cleansing. The formation of scum wastes soap. In industrial plants this waste is very costly. Another objection to hard water is that it deposits its minerals on the walls and in the tubes of boilers. This rocky lining, or scale as it is called, is a poor conductor of heat. Considerable heat is therefore lost in boiling the water. Indeed, it has been estimated that a deposit one-quarter of an inch thick on the tubes of a boiler will increase the amount of fuel used by almost 50 percent. See Fig. 6–2.

Water can be softened by adding washing soda, or sodium carbonate, to it. The sodium carbonate forms an insoluble compound with the dissolved minerals so that the hardness is removed. For some types of hardness, lime, which is much cheaper than washing soda, is commonly used.

Demonstration 6–1. To Harden and Soften Water.

Almost fill a test tube with distilled water. Add a few drops of calcium chloride solution to harden it. Now pour half of the water into another test tube. Half fill a third test tube with distilled water and place the three test tubes in a rack.

Pour a little soap solution into the tube containing distilled water and also into one of the tubes containing hard water. Shake the tubes. Notice the formation of a scum and also the small amount of suds in the hard water.

Now soften the hard water in the remaining tube by adding a little sodium carbonate solution. Filter the water to remove the precipitate. Pour a little soap solution into the softened water and shake. Observe that there is considerably more lather than in the hard water.

Drinking Water. As human beings, we require large quantities of water. Most of it comes from rain water that falls on the land, seeps through the soil, and eventually joins a stream, river, or lake from which we get our drinking water.

As we shall see in a later chapter, the soil contains a vast number of microbes and bacteria—some harmful, some helpful. Typical harmful microbes are the typhoid germ and the dysentery germ. Both can live in water. If they are present in the water we drink, they enter our intestines, where they thrive and multiply. A person with typhoid germs in his intestines may suffer from typhoid fever, which is a dangerous and often fatal disease. Moreover, if the germs are in a source of public drinking water, there may be a serious outbreak of typhoid throughout the community. A generation or so ago typhoid was common in the United States, but as a result of careful examination and purification of drinking water the disease has almost been wiped out.

Supplying drinking water for a large city is a major problem for engineers, bacteriologists, and chemists. The regular daily requirement of water is enormous; normally about one hundred gallons per person per day are provided. New York City, for example, uses almost one billion (1,000,000,000) gallons of water per day.

Drinking water for cities is collected from watersheds—drainage or catchment areas in sparsely populated regions. Every precaution is taken to see that the water is not polluted by sewage, since sewage is always a possible source of typhoid germs. New York City draws water from four different watersheds in the Catskill and Adirondack mountains.

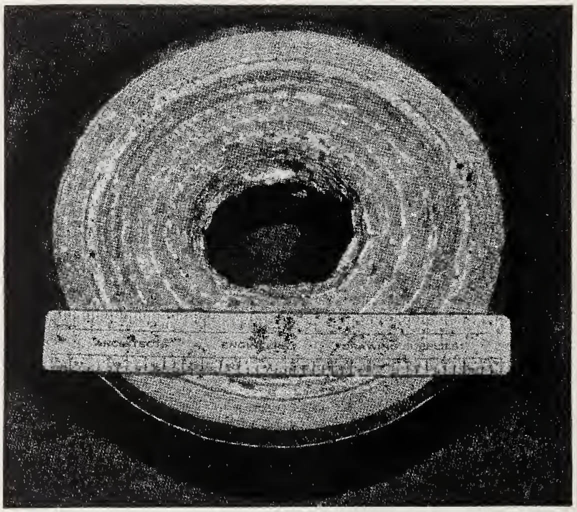
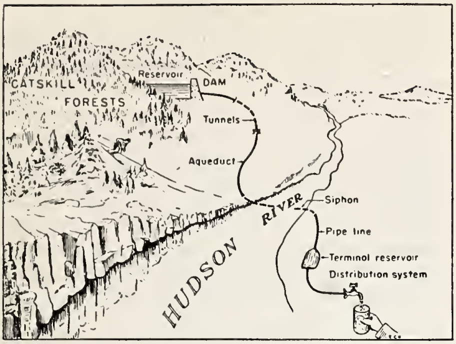


Fig. 6–2. Scale formation inside a hot-water pipe.



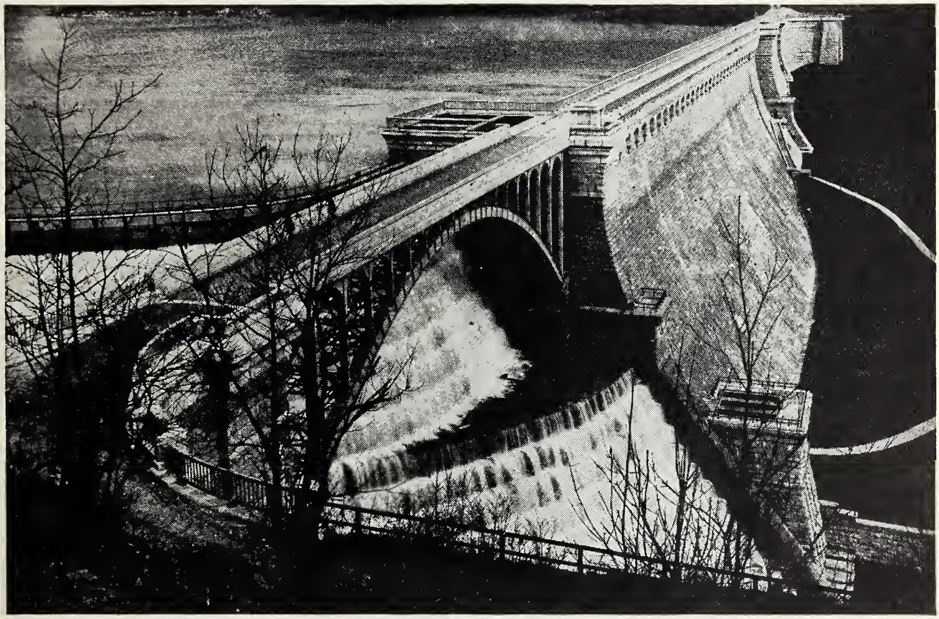
Courtesy U.S. Forest Service

Fig. 6–3. New York City obtains its water from forested watersheds.

Water is drained from the watersheds and stored in reservoirs. Reservoirs are artificial lakes in which the water is stored usually behind a concrete dam constructed at the lower end. During the spring rains the maximum amount of water is collected in the reservoir so that there will be a steady supply of water during the dry season. The reservoir also helps to purify the water, since organisms and organic matter in suspension slowly settle in its quiet waters.

From the reservoir the water is carried, usually by underground aqueducts, to the city filtration plant, where the real purification takes place.

The Purification Process. The purification process depends on the nature of the raw water obtained from the reservoir. When the operation is complete, the *water should be clear, soft, free from objectionable odor and taste, and free from harmful bacteria.* Puri-



Courtesy City of New York, Department of Water Supply

Fig. 6–4. Croton Dam forms one of the reservoirs supplying New York City with drinking water. In the rainy season the reservoir overflows and the excess water is discharged over the weir on the left of the picture.

fying water involves five different treatments. These are: (1) sedimentation, (2) filtration, (3) aeration, (4) lime-soda treatment, and (5) chlorination.

① In the sedimentation process the raw water is run into concrete basins about 15 feet deep. Alum is then added to the water. It reacts chemically with the water to form a jellylike mass which slowly settles and carries most of the mud and bacteria to the bottom of the basin. The basin is thoroughly cleaned about once a month to remove this deposit. After standing for two or three hours in the sedimentation basin, the water is run to the filter plant.

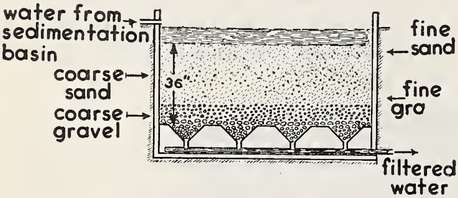


Fig. 6–5. A unit in the filter plant. Filtration is part of the purification process of drinking water.

Demonstration 6–2. Sedimentation.

Almost fill two glass cylinders (hydrometer jars) with water. Add a little ammonium hydroxide to each jar so that the water is slightly alkaline by the litmus test (that is, until red litmus paper dipped into it turns blue). Add some fine sand, dirt, and powdered clay (kaolin) to both jars, and stir. Into one of the jars pour about 20 cc. of a solution of aluminum sulfate. Allow the jars to remain undisturbed overnight. Notice that the sediment in the jar with aluminum sulfate has been carried to the bottom by the formation of a jellylike substance.

② *Filtration* is performed in a *filter plant* consisting of a number of units similar to the unit shown in the diagram. It contains fine sand at the top, then coarser sand below, and gravel at the bottom, to a total depth of about three feet.

Water from the basin runs in at the top. The sand is an effective filter so that the water which escapes at the bottom is freed from all sediment and most of the bacteria. It is important to keep the filters clean, and they are usually cleaned every day. To clean them, water is forced in at the bottom, and the wash water escapes at the top and is rejected.

③ *Aeration* is the third step in the purification

Courtesy City of New York, Department of Water Supply

Fig. 6–6. The Ashokan aerator which purifies the New York City drinking water. Jets of water are thrown into the air from about sixteen hundred nozzles. In this way impurities are oxidized so that objectionable tastes and odors are removed from the drinking water.

of water. The water is cascaded over an artificial waterfall or thrown into the air through jets. In this way the water is exposed to sunlight and air to remove any offensive odors or tastes.

4 The *lime-soda treatment* follows. After the water has been analyzed to determine the hardness, lime and soda are added as necessary to soften the water.

The final operation in purifying water is 5 *chlorination*. This is a process of bubbling chlorine gas through the filtered water. As stated in Chapter 3, chlorine is a poisonous gas. Only a small amount is used—enough to kill any remaining bacteria but not enough to be harmful to human beings. After this, the water is free from contamination and fit to drink.

Although the five steps in the treatment of water are called a purification process, they do not result in *pure* water, but rather in safe, drinkable water. By pure water, we mean water containing no substances in solution. Drinking water contains much soluble material. Indeed, these harmless substances in water make it palatable. To obtain pure water, all dissolved solid impurities must be removed by a process known as *distillation*.

Distillation. If a solution is boiled, water vapor escapes and the solid impurities are left behind. If the water vapor is sent through a condenser (which is a tube surrounded by a cold-water jacket), the vapor is converted back to water—pure distilled water.

Demonstration 6–3. Distillation of Sea Water.*

The distillation apparatus consists of three parts: the boiler or distilling flask, the condenser, and the receiver. Half fill the flask with sea water and set up the apparatus as shown in Fig. 6–7. Boil the water and collect some of the condensed vapor. Taste the distilled water. It has no flavor because it contains no dissolved solids.

Pollution of Water. Ever since the first towns were established, it has been common practice to dump sewage into streams. So long as the town remained small, the stream was able to carry off the wastes and to oxidize them, by its dissolved oxygen, into harmless substances. As towns grew in size and the amounts of wastes increased, this process of self-purification became impossible. The result was that the streams were polluted and became a menace to public health. This situation has also been aggravated by the disposal of wastes from industrial plants into the streams.

The pollution of streams has now become a national problem. Most states have antipollution laws which limit the amount of organic wastes that may be discharged into a stream. But such laws are of little use unless adequate provision is made for the treatment of sewage.

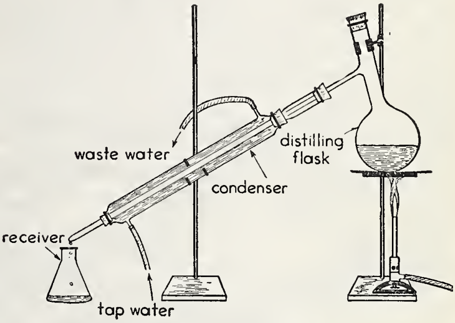


Fig. 6–7. Distillation.

The purpose of sewage treatment is to remove sufficient impurities to render the water harmless. The most common type of purification plant is one in which the solids are filtered and treated with a sludge containing bacteria. The bacteria oxidize the organic matter into nitrates, which can then be used as fertilizer. One such plant for treating sewage is shown in Fig. 6–8.

Relatively few cities provide enough plants for the treatment of all the sewage, and some sewage is still dumped into a nearby body of water. This practice has serious results. The water is made unfit for swimming; land in the vicinity of the water becomes undesirable; fish life in the streams is often destroyed; and an epidemic of typhoid fever is a possibility. It has been estimated that in the United States the damage caused by the pollution of streams amounts to $100,000,000 a year.

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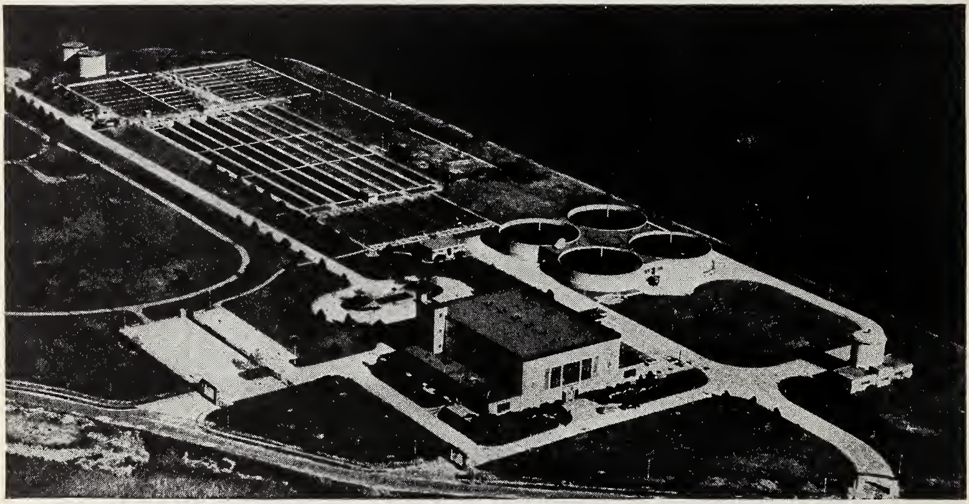
* A salt solution can be substituted for sea water.

Water Conservation. It is apparent that the health of a community, its development, and even its prosperity depend on an abundance of clean water. Water is one of the nation's important natural resources, and its conservation is now recognized as a national problem.



Fairchild Aerial Surveys, Inc.

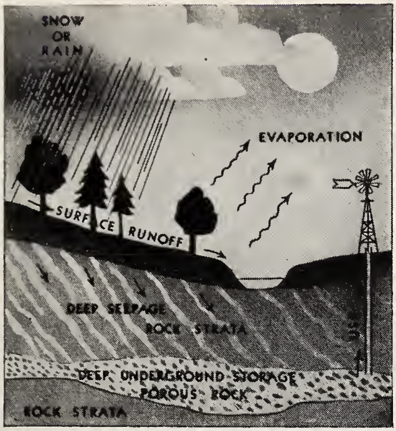
Fig. 6–8. Tallmans Island Sewage Plant, one of the New York City sewage plants. It treats about 22 million gallons daily.

The best way to conserve water is to start where the rain falls on the ground, that is, on the watershed from which a stream gets its water supply. The watershed ought to be liberally covered with trees, shrubs, and grass. The plant growth holds the water; it prevents the rain from running rapidly over the surface and washing away the valuable topsoil; it helps the water to sink into the ground.

Some of the water that seeps into the ground is absorbed by the roots of plants; the rest flows underground to feed the streams. A watershed is therefore a vast natural reservoir that collects rain water and insures a steady and abundant supply of water. If watersheds are damaged by fire, by careless or excessive cutting of timber, or by overgrazing, our water supplies will be impaired. In addition to storing water, watersheds are useful for hunting and fishing, for the grazing of livestock, and as a source of timber.

In the past our natural water resources have been abused. Inland fisheries, which can provide a much higher yield of the nation's food supply, have declined. The reasons for this are overfishing, the blocking of streams by dams, the washing of land into lakes and rivers, and the pollution by sewage and industrial wastes.

The Composition of Water. In Chapter 3 we stated that water is a compound of hydrogen and oxygen, and that the bonds which hold these elements together are exceedingly strong and difficult to break by chemical means. The bonds can be broken rather easily, however, by an electric current, provided a little sulfuric acid is added to the water to make it a conductor. The apparatus needed for this experiment is shown in Fig. 6–10.



Courtesy U.S. Forest Service

Fig. 6–9. A watershed with good plant cover acts like a blotter, soaking up water and preventing the erosion of top soil.

Demonstration 6–4. The Decomposition of Water.

Solder small pieces of platinum foil to the ends of two copper wires. Bend the wires into a beaker as shown in the figure. Pour dilute sulfuric acid into the beaker until the platinum terminals are covered. Fill two test tubes with water; invert them, placing the open ends under the water in the beaker, and support them over the terminals. Attach the wires to a source of direct current supplying about 8 volts.

Bubbles of gas appear on each of the terminals and are collected in the test tubes. Notice that one tube contains twice as much gas as the other. When this tube is about three-quarters full of gas, break the current. We will now proceed to test these gases for hydrogen and oxygen.

Hydrogen burns, and the burning makes a satisfactory test for the gas. With the thumb close the tube containing the greater volume of gas. Withdraw the tube from the beaker, hold the tube erect, and remove the thumb. Now, holding the tube with clamps, place the open end near the Bunsen flame. Notice that the gas burns; therefore it is hydrogen.

Oxygen gas relights a glowing splint but does not burn. Withdraw the other tube in the same manner. Plunge a glowing wooden splint into the gas and notice that the splint burns. This test proves that the gas is oxygen.

It follows that *water can be decomposed into hydrogen and oxygen, the volume of hydrogen being twice the volume of oxygen.*

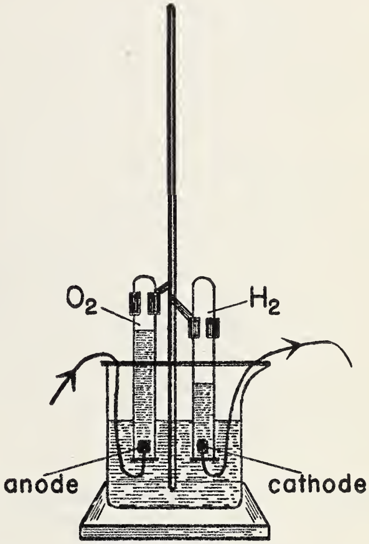


Fig. 6–10. Decomposition of water by electricity.

THE SEAS

Distillation in Nature. Thus far we have barely mentioned such enormous reservoirs of water as the seas or oceans. Water covers almost three-quarters of the earth's surface. If it were evenly distributed, it would cover the whole earth to a depth of two miles. How does the water get from the sea to the land? This process is part of a natural circulation system—a distillation system on a large scale.

When the sun warms the surface waters of the seas, evaporation takes place and water vapor rises into the air. The vapor is carried away by winds. At high altitudes some of it partly condenses to tiny droplets, forming clouds. If the clouds are cooled, the droplets condense to form rain. The process will be discussed in Chapter 19.

The rain that falls on land washes over rocks and soil. In so doing, as you know, it dissolves some of the soluble ingredients. Most of the water on the land drains into brooks and streams; these, in turn, become tributaries of larger rivers, which empty into the sea. Notice, however, that the rivers are not pure water; they contain substances in solution and in suspension. The sun's heat evaporates only the water. We would therefore expect that the sea is becoming more and more concentrated with dissolved material. A change in the concentration of sea water is, of course, a slow process, and it would take at least a million years to show a marked increase. At the present time, however, the solids in solution amount to about 3½ percent by weight. In other words, if 100 pounds of sea water are completely evaporated, the solid residue will weigh about 3½ pounds. You can check this figure by evaporating a large sample of sea water if it is available.

Different Kinds of Natural Water. It is now clear that we can separate natural waters into three groups: (1) rain water, (2) ground or surface waters, and (3) sea water.

① *Rain water* is the purest of the natural waters since it is simply condensed water vapor. It is not a convenient source of drinking water, yet it is used in places like Bermuda where there is no other source of fresh, or drinkable, water. There the rain water is collected on the flat white roofs which are designed for the purpose. Because rain water is soft, it would be suitable for factory use, but it is not practical to collect and store it in sufficient quantities.

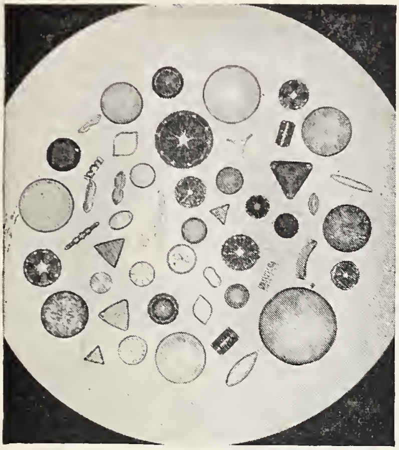
② *Surface waters* are fresh waters and include streams and lakes. The amount of solid they have in solution depends on the kind of soils and rocks over which they flow. If a river flows over granite, which is an almost insoluble rock, the water contains relatively little dissolved solid. As a rule, however, river water contains a large number of elements (in the form of compounds) in solution. The most common of these elements is calcium.

③ *Sea water* receives the dissolved solids from surface waters, and its disagreeable taste is due to these substances in solution. The elements that are fairly plentiful in sea water are potassium, magnesium, calcium, sulfur, phosphorus, and bromine—all, of course, in compounds. By far the most abundant element, however, is sodium, which is present in the form of sodium chloride, or salt.

Here is an interesting paradox. The most abundant element in surface waters is calcium; surface waters run into the sea; yet the most abundant element in sea water is sodium. These are facts that cannot be denied, but they do not seem to make sense. How do we account for the apparent disappearance of calcium in sea water?

Sea Animals Remove Calcium from Sea Water. Many small animals that live in the sea protect themselves against fish by growing hard shells of lime, or calcium carbonate. In this way enormous quantities of calcium are constantly being used up by hard-shelled animals that live on the sea bottom. Indeed, geologists have calculated that about 1,400,000 tons of calcium are removed in this way every year. The chalk in the white cliffs of Dover are composed largely of the shells of microscopic animals that once lived in the sea. The formation of rocks from these once-living creatures will be discussed further in Chapter 11.

We must not think, however, that calcium is the only substance removed from sea water. The mineral silica, which occurs in sand and is known as quartz, is removed by microscopic plants called *diatoms*, which float on the surface of the sea. We shall tell more about diatoms in Chapter 26. At this point we shall merely state that they are the basic food of fish in the sea. They build exquisitely shaped skeletons of silica that support their softer parts. Fig. 6–11 shows a group of diatoms that have been magnified about a hundred times and photographed.



Ward's Natural Science Establishment, Inc.

Fig. 6–11. Diatoms.

The Sea as a Storehouse. The sea is a storehouse for everything washed from the land. Consequently sea water contains practically every known element in one compound or another. Some elements are much more plentiful than others, but all the elements are present. One cubic mile of sea water contains, in addition to many other substances, all of the following in the form of compounds:

	Tons
Sodium	40,000,000
Magnesium	5,500,000
Calcium	1,700,000
Potassium	1,600,000
Bromine	270,000

What is the value of these substances in the sea? Can they be recovered so that we can use them? The world's minerals are being used up rapidly. World War II in particular made a great drain upon them. Already there is a world shortage of copper, tin, lead, and tungsten. Minerals cannot be renewed like things that grow, such as trees, for instance. Some day chemists will have to turn to the sea for the metals that are needed.

Salt, of course, has been obtained by the evaporation of sea water since earliest times. Today salt is needed in many industries, but in most countries it is easier to mine the salt from deposits in the earth than to evaporate it from sea water. Salt deposits are the remains of inland seas that dried up ages ago. They are found in many of the states, particularly in New York, where salt is plentiful fairly near the surface.

The element bromine was the first of the scarce elements to be extracted from sea water. Bromine is needed in the antiknock liquid that is added to gasoline. At one time the only large mineral source of bromine was owned by the Germans, who charged a very high price for it. Shortly after World War I bromine was extracted from sea water. Today sea water is the source of practically all the bromine used in the United States. About one pound of bromine is obtained from 4,000 gallons of sea water. This means that to produce five tons of bromine a day, 40,000,000 gallons of sea water must be treated. This is a major engineering problem and indicates only one of the difficulties involved in extracting substances from sea water.

The only other element so far obtained from sea water is magnesium. The need for magnesium in airplane construction in World War II prompted the building of a plant for extracting this element from sea water. Sea water contains about 1 part magnesium in 800 parts water. From one ton of sea water, therefore, about 2½ pounds of magnesium can be obtained.

These two processes point the way to future industries. Extraction of substances from the sea is an expensive operation, because powerful pumps are needed to force vast quantities of water through the factory from which relatively little of the element is obtained. Nevertheless, as metals become scarcer and prices rise, the extraction method will be able to compete with the present industrial processes, which usually consist of mining the ore—often far below the surface—and then obtaining the metal in a blast-furnace operation.

THINGS TO REMEMBER

Water is *present in all foods;* it is needed in the life processes, and is required in most industries.

The following processes are usually necessary to convert *raw water into drinking water:* (1) sedimentation, (2) filtration, (3) aeration, (4) lime-soda treatment, (5) chlorination.

Hard water is caused by calcium or magnesium salts in solution; they can be removed by lime or washing soda.

Water pollution is caused by sewage and industrial wastes. Polluted water can be rendered harmless in purification plants.

Water is an important *natural resource.* The nation's health and prosperity depend on water conservation.

Distillation involves boiling the solution and condensing the vapor.

Water can be *decomposed* to give two volumes of hydrogen and one volume of oxygen.

Sea water consists of about 3½ percent solids in solution.

Natural waters may be classified as: (1) rain water, (2) surface waters, (3) sea water.

Calcium is the most abundant element in surface waters; *sodium* is the most abundant element in sea water.

Sea water is a great storehouse of minerals. At present, however, only sodium chloride, bromine, and magnesium are obtained from it.

QUESTIONS

A

1. State some of the effects of water pollution.

2. Describe at least three uses for water in industrial processes.

3. What is: (*a*) hard water; (*b*) soft water?

4. Explain how typhoid germs can get into river water.

5. What is the most effective way of destroying harmful bacteria in drinking water?

6. What is meant by the term *distillation?*

7. (*a*) How would you classify natural waters?
(*b*) Which type contains the most solids in solution, and which the least?

8. What are diatoms?

B

9. (*a*) Discuss two objectionable features of hard water.
(*b*) How can hard water be softened?

10. Explain how water should be treated before it is fit for drinking.

11. Describe an experiment by which you could prove that water is a *compound* of hydrogen and oxygen.

12. Sea water contains a smaller proportion of calcium than river water. Why?

13. (*a*) What elements are obtained from sea water and why?
(*b*) Explain two difficulties involved in extracting substances from sea water.

14. What is meant by water conservation? Why is it necessary?

PROJECTS

1. *Visiting a City Water Purification Plant.* A visit to the local municipal purification plant is worth while. Find out the location of the watershed and how the water is brought from it to the plant. Examine the different purifying processes *in order.* Notice how the drinking water is stored and protected before it is piped to the city.

Finally, notice how the water is pumped into the standpipe, and observe that the water level in the standpipe is high enough to cause sufficient pressure at the faucets in the city houses.

Make a written report of the visit; literature is often supplied at the plants that would help you in preparing it.

2. *Investigating Your Local Sewage System.* Are the sewage and industrial wastes dumped into a river in your community? Is the current strong enough to carry the refuse away? If you have a local purification plant, visit it. How are the solids disposed of? Where does the clean water join the river?

Your municipal engineer will probably be glad to help you with this project.

Chapter 7

WATER FOR MACHINES

Water serves man in many ways. In addition to supporting life, it supplies steam to run locomotives and to heat houses; it turns water wheels and electric generators, thereby providing two sources of power; it irrigates desert regions, making land fertile and increasing enormously the productive capacity of the earth. To achieve these purposes, man has found ways to put water to work. He has built ships that developed commerce between nations; he has invented turbines so that water power has replaced manpower and horsepower in the operation of many machines.

In this chapter we are concerned with the use of water and other liquids in machines that aid man in doing his daily work. What are these machines and how do they work? To answer these questions, we must first examine some of the properties of water.

Water Exerts a Pressure. The molecules of water slide past one another so easily that water cannot maintain a shape. In other words, water must be held in a container. Water pushes against its container with considerable pressure. Thus water in a tank on top of a building can supply pressure to all the faucets in the building. The faucets in the basement have the greatest pressure because they are the farthest below the water level in the tank, and any faucet higher than the tank will have no pressure at all. In fact, the water will not even rise to the level of the faucet (see Fig. 7–1).

The increase of pressure with depth makes it difficult for man to go very far below the surface of the ocean. A professional deep-sea diver in a special suit can go down 300 feet. William Beebe, using a steel ball, reached a depth of 3,000 feet. In 1949 Otis Barton, a colleague of Beebe's, reached a depth of 4,500 feet. At this depth in the ocean the pressure of the water is almost 2,000 pounds per square inch, or nearly 135 times as great as that of the atmosphere at sea level. This tremendous pressure is exerted equally in all directions.

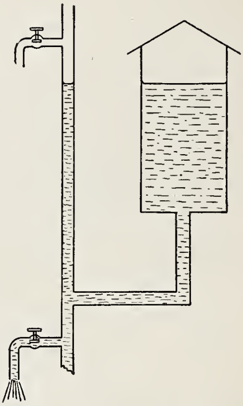


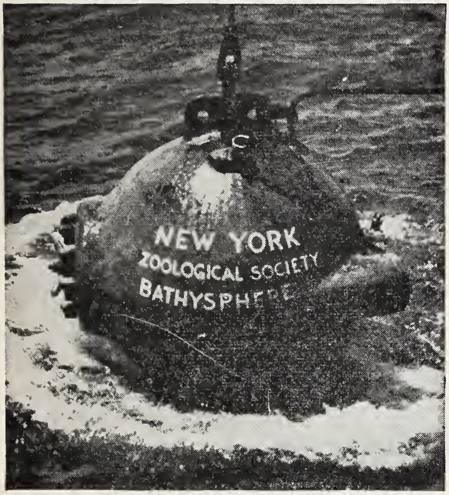
Fig. 7–1. A water tank supplies water to faucets below it.

Sideways and Upward Pressure. Water pushes sideways as well as down. This fact is familiar to anyone who has tried to keep water from leaking through the walls of a cellar. Water also exerts an upward pressure, as is shown by the little fountain that gushes up through a hole in the bottom of a leaky rowboat. Thus water is much more difficult to confine than, say, a stack of books, which need be supported only from below. *Water requires a container.*

Demonstration 7–1. Direction of Water Pressure.

Fill a gallon tin can with water and insert a glass tube in the stopper, as shown in Fig. 7–3. Fill the tube with water. Punch a small hole in the top of the can and see how high the water will spurt out. Why does this experiment indicate that water exerts an upward pressure?

Now punch four holes in one side of the can at various distances from the top. Describe the differences in the streams of water. Do they illustrate the sideways pressure of water? Which stream shows the greatest pressure?



Courtesy Dr. William Beebe

Fig. 7–2. Heavy steel bathysphere used by Dr. William Beebe to study ocean life at a depth of 3,000 feet.

The Trenche Dam, shown in Fig. 7–4, is only 25 feet thick at the top. At the base it is 250 feet thick in order to withstand the tremendous sideways pressure of the water 235 feet below the surface of its reservoir. What is the pressure at the base in pounds per square inch?

Water is Incompressible. In spite of the fact that water flows easily, it is almost incompressible; that is, it cannot easily be squeezed into a smaller volume. In this it differs from air, which is easily compressed.

Demonstration 7–2. The Incompressibility of Water.

Plug solidly the opening at the bottom of a bicycle pump. Then push down on the piston and notice that the air inside the pump can be compressed to a small fraction of its original volume.

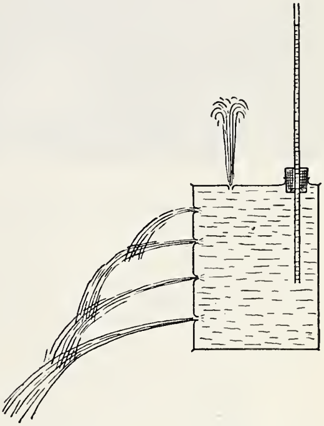
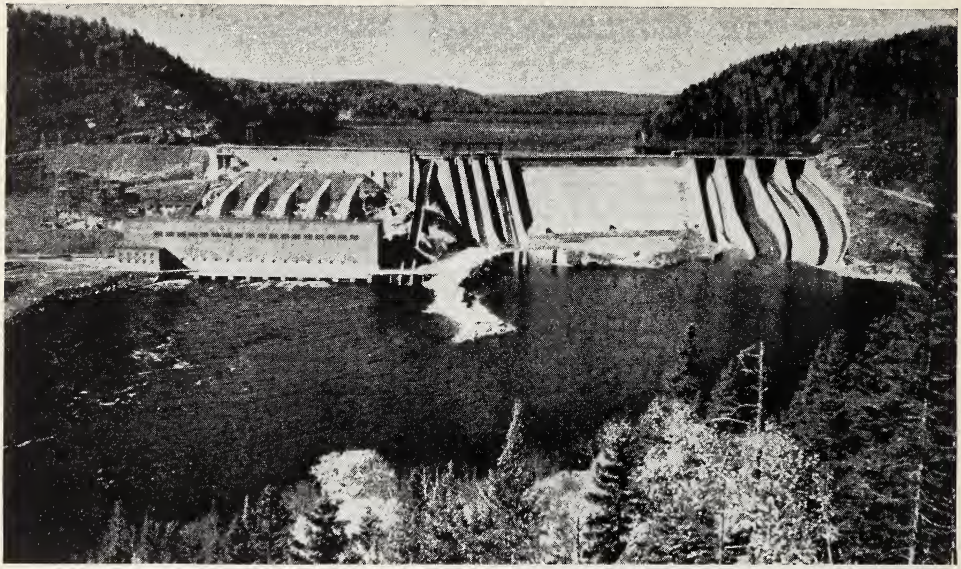


Fig. 7–3. Water squirts from holes in a gallon can.

Now fill the pump with water and insert the piston so that no air remains below it. Again push down on the piston. This time the piston hardly moves, and even a blow with a heavy hammer will cause little compression.

This property of incompressibility of water can also be shown in another way. Bend a 20-inch length of glass tubing into a U-shaped tube with similar arms. After the tube has cooled, fill it halfway with water. Observe that the level of the liquid is the same in both arms of the tube. Now, with a smoothly fitting piston made by wrapping string around a glass rod, push the water in one side of the tube down about one inch, as in Fig. 7–5. The water in the other arm rises by the same amount so that the difference in water levels becomes two inches. Why does



Courtesy the Shawinigan Water and Power Co.

Fig. 7–4. The Trenche Dam on the St. Maurice River, Quebec. This dam, which has a capacity of 325,000 horsepower, is one of six on the river, making it one of the most fully developed power sources in the world

this experiment show that water is incompressible?

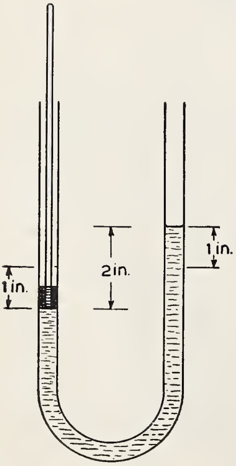


Fig. 7–5. Water is incompressible.

The same result may be obtained by blowing gently into one arm of the tube. The harder you blow, the greater the difference in water levels. In fact, the difference in water levels in connected tubes is frequently used as a measure of the gas pressure applied to one of the surfaces. Such a device, shown in Fig. 7–6, is called a *manometer*. It is often used for measuring small pressures.

Demonstration 7–3. Measuring Gas Pressure.

Mount the U-tube manometer near an inch scale as shown in Fig. 7–6. Half fill the tube with water to which a little red ink has been added.

Connect rubber tubing from the gas outlet in the laboratory to one end of the manometer and open the gas cock slowly. What is the difference in the water levels? How much above atmospheric pressure is the gas pressure in inches of water? What fraction is this of normal atmospheric pressure? What is this pressure in pounds per square inch? Could this manometer be used to measure the pressure in the water faucet?

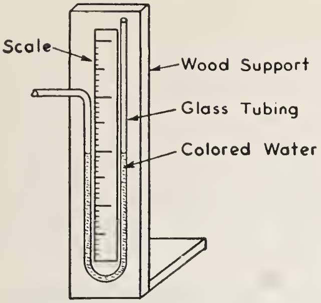
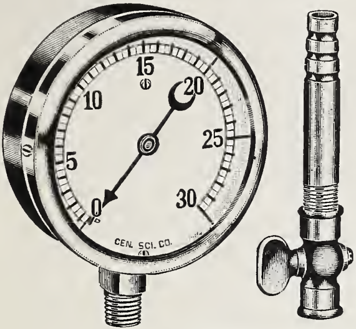


Fig. 7–6. A water manometer.

A Bourdon Gage. Since a manometer contains an exposed liquid, it is inconvenient for general use. Instead, another instrument, the Bourdon gage, shown in Fig. 7–7, is more commonly used. It consists of a curved hollow tube. When pressure is applied to it, the tube straightens out and the end of the tube moves a pointer over a scale that indicates the pressure.



Courtesy U.S. Gage Co.

Fig. 7–7. A Bourdon gage.

Water Transmits Pressure. Water not only exerts a pressure because of its weight, but it also transmits any additional pressure applied to it. This applied pressure is exerted on all parts of the container holding the water.

Demonstration 7–4. Transmission of Pressure.

Connect lengths of pipe and T-connectors to form a 10-foot length, with Bourdon gages attached and a faucet on the end, as shown in Fig. 7–8. The gages should read 0 to 50 pounds per square inch, or enough higher to measure the water pressure in the laboratory faucet. Connect the pipe to the faucet by a length of strong garden hose and fill it with water. Examine the gages; they should all read zero. Then, with the outlet faucet closed, open the laboratory faucet a little until each gage shows a reading. Record these readings. Now open the laboratory faucet again to produce a somewhat higher reading on the gages and record these readings. How much has each gage reading changed? Have all the readings changed by the same amount?

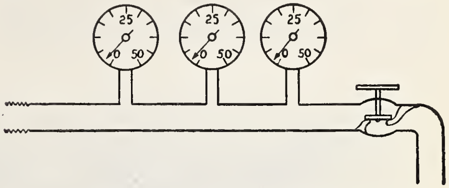


Fig. 7–8. An experimental pressure system.

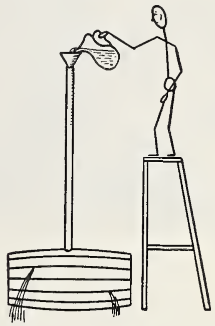


Fig. 7–9. How Pascal broke open a barrel with a pitcher of water.

When the laboratory faucet is opened, the water pressure in the faucet is applied to the water in the pipe and should be transmitted to all the gages, so that the *increase* in reading should be the same for all.

Blaise Pascal, a French scientist who studied the transmission of pressure in liquids, stated that if pressure were applied to water in a wine cask, the cask might be split wide open. He argued that if the pressure were only 10 pounds per square inch, the surface inside the barrel would be subject to this pressure on *every* square inch. If there were, say, 1,000 square inches of area inside the cask, the total force would be 10,000 pounds, since the total force is pressure multiplied by the area. He performed the experiment by first inserting a long narrow tube in the side of a cask that was already full of water. Then he poured water from a pitcher into the long tube as shown in Fig. 7–9. When the water reached a height sufficient to provide the necessary force, the cask did indeed split at the seams and the water rushed out.

Hydraulic Press. Today we use this principle in a powerful machine called a *hydraulic press.* A small laboratory model of the press is shown in Fig. 7–10. The one shown in Fig. 7–11 is a commercial press capable of exerting a force large enough to shape in one operation a sheet of steel into the roof of a car.

The principle governing the operation of such a press is illustrated in Fig. 7–12. Assume that the small piston p has an area of 1 square inch and that a force of 10 pounds is applied to it. The piston then exerts a pressure of 10 pounds per square inch upon the liquid (usually oil) under it. This pressure is transmitted in all directions by the liquid. Now assume that the large piston has an area of 1,000 square inches. Since it is subjected to the pressure of 10 pounds per square inch produced at p, the total force on the large piston is 10,000 pounds.

Such a tremendous force may be very useful, especially since it can be easily controlled by the movement of the small piston. Many automobile lifts in service stations operate on the same principle. So do barbers' chairs, which usually have a small hydraulic lift in the base

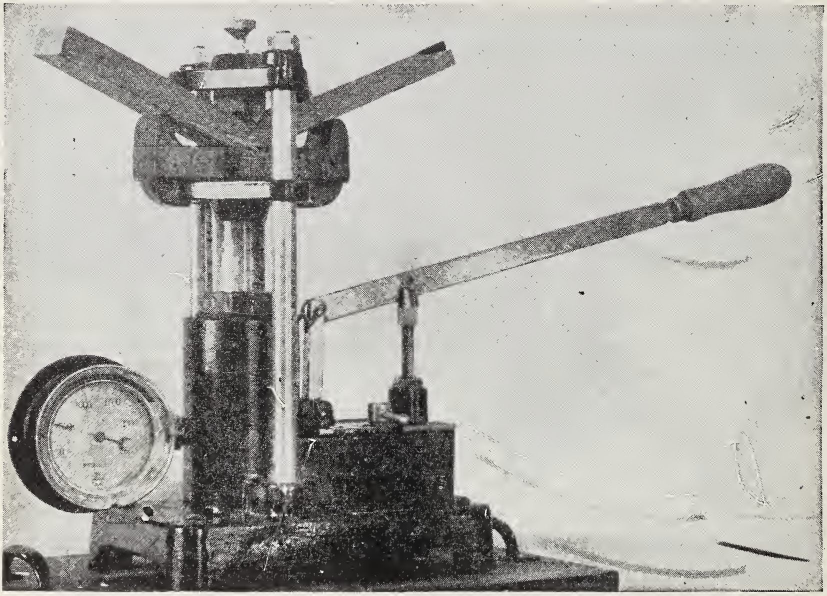
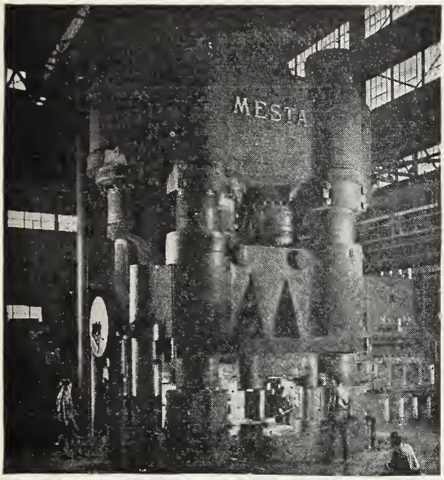


Fig. 7–10. Laboratory model hydraulic press.

Modern automobiles usually have hydraulic brakes like those shown in Fig. 7–13. When we step on the brake pedal, the force acts on a master piston which multiplies that force and transmits it to the brake piston on each wheel. If the brake pistons have the same diameter, the force on each piston, and therefore on each wheel, is the same. This application of a large, steady force to all the wheels is a safe and sure means of stopping the car.



Courtesy Wyman-Gordon Prod. Co.

Fig. 7–11. A commercial hydraulic press.

Mechanical Advantage. The force overcome by a machine is usually larger than the force applied to it; the ratio of these forces is called the *mechanical advantage* of the machine:

$$\text{Mech. Advan.} = \frac{\text{Force overcome (resistance)}}{\text{Force applied (effort)}}$$

In the hydraulic press described above, the mechanical advantage equals $\frac{10{,}000\ \text{lb.}}{10\ \text{lb.}}$ or 1,000. In other words, the force produced is 1,000 times as large as the force applied. Note that this is the same as the ratio of the *areas* of the pistons.

The Flow of Liquids. The pressure exerted by water is reduced as the water flows through pipes. This is due to the fact that the inner surface of the pipe and the bends and joints all produce friction that opposes the flow of the water and thereby reduces the pressure. The longer and smaller the pipe, the more noticeable is the effect of friction.

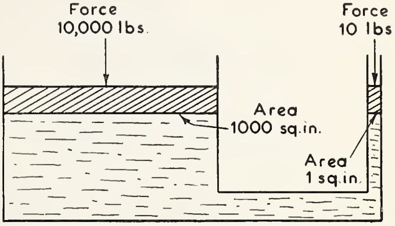


Fig. 7–12. Principle of the hydraulic press.

Demonstration 7–5. Reduction of Pressure by Friction.

Connect the long pipe described in Demonstration 7–4 to the laboratory faucet and open the faucet wide. Close the outlet faucet on the pipe and read the gages. Now open the outlet faucet slightly and read the gages again. Open the outlet still wider and read the gages once more. Do they all read the same? Do they read less when the outlet is wide open or when it is closed?

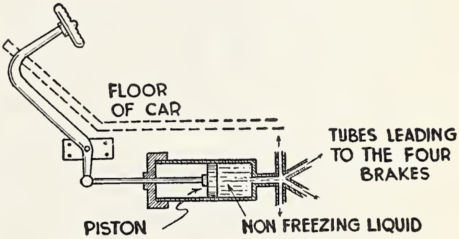


Fig. 7–13. Principle of hydraulic brakes.

When the faucet on the pipe is closed, all the gages read the same high value: the pressure of the water supply. When the faucet is opened, the water rushes through the pipe and the pressure drops all along the line, but the drop increases as the water proceeds along the line of flow.

This effect is often apparent in the small pipes of old houses. If water is being used on the first or second floor, the third-floor faucets may be unable to supply any water. When the lower faucets are closed, enough pressure builds up to send the water to the higher floors.

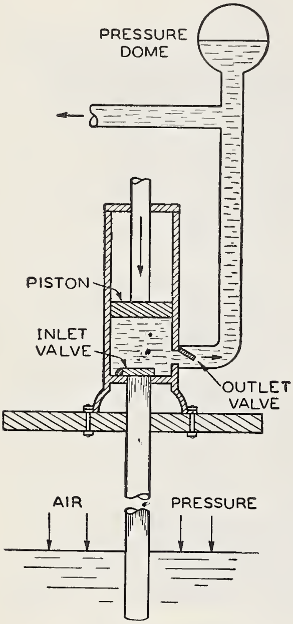


Fig. 7–14. A force pump.

A TOWN WATER SYSTEM

Fresh water for drinking, for washing, and for fire fighting is a necessity in all towns and cities. This water is usually piped from a reservoir, which may be many miles from the town. To move the water through the pipes, sufficient pressure must be produced at the water works to overcome the friction in the pipes. If the original pressure is not great enough, or if the pipes are too small, the water pressure will drop very low when large quantities of water are being used—as at a fire, for instance. If this happens, it may be impossible to send a stream of water to the upper parts of a burning building.

A Water Tower. If the reservoir is higher than the town, the water can flow by its own weight through the pipes to the town. But even then the water works usually do not have water enough to meet peak demands. Water is therefore stored in a water tower or standpipe. Standpipes are built on hills or on high towers so that they will produce a high pressure for the faucets in town.

Water Pumps. The water must be forced up into the standpipe, however. For this purpose pumps are used. A simple type of pump, called a *force pump* (see Fig. 7–14), is operated as follows. When the piston moves upward, away from the inlet of the pump, a partial vacuum is produced between the piston and the inlet valve; then the air pressure outside forces water to enter the pump through the inlet valve. When the piston is then moved downward, the pressure closes the inlet valve and forces open the outlet valve through which the water is expelled with a force great enough to carry it to the standpipe. A *pressure dome* is usually connected to the outlet of the pump to smooth the flow of water. During the pressure stroke of the pump, water is forced into the pressure dome, compressing the air inside it. On the intake stroke of the pump, the air in the pressure dome forces the water out, thus maintaining a more continuous flow of water through the pipe.

Another kind of pump, called a *lift pump*, often used on farms for lifting water from a well, is shown in Fig. 7–15. In this, water is pushed into the pump by atmospheric pressure when the piston is raised. When the piston is lowered, the inlet valve closes, and water is forced through a valve in the piston and into the upper part of the pump. When the piston is next lifted, the water above the piston is

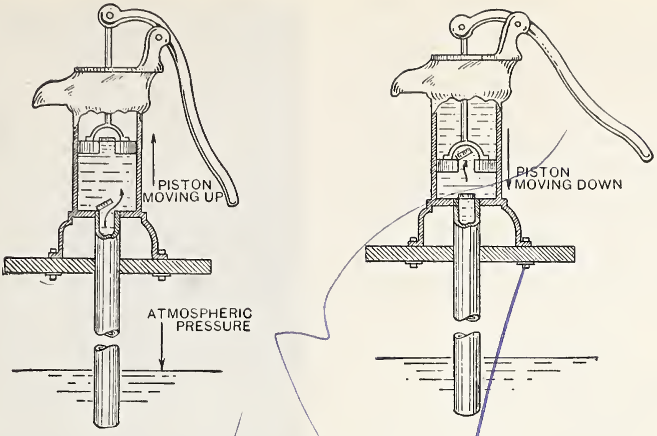


Fig. 7–15. A lift pump.

raised to the spout as new water enters the body of the pump from the well.

Both the force pump and the lift pump depend on atmospheric pressure to push the water into the body of the pump when the piston is moved. If the pump is more than about 30 feet above the water surface, the lifting effect of atmospheric pressure is not great enough and water does not reach the valves or piston. (A pump with perfectly fitting pistons *could* work up to 34 feet above water level. Why does this not happen in actual practice?) Therefore pumps are often set down inside deep wells, as in Fig. 7–16. This is especially necessary in arid regions, where the water level in the well ~~may~~ fall markedly during the dry season. Pumps used in mines are always located deep down in the earth where the water seeps through the rocks and collects in pools. These are force pumps, since the water must be forced up from the bottom of the well or mine.

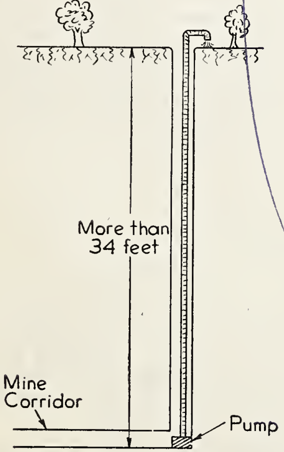


Fig. 7–16. Pumps are located near the bottom of deep wells or mines.

A third type of pump is the *centrifugal pump*; one is shown in Fig. 7–17. In this type, water enters near the center of the pump and is caught by rapidly whirling vanes which throw it to the outside of the pump with such force that it continues through the outlet tube with considerable velocity. Such pumps cannot force water to a great height, but they can deliver a large quantity of water in a smooth-flowing stream.

POWER FROM WATER

Water Wheels. Until about fifty years ago, mills were often located on swift-flowing

Good-bye Sylvia [illegible]

streams because the water in these streams could be used to drive the machines of the mills. Most of the old-fashioned *water wheels,* like the one shown in Fig. 7–18, received the water on top and the weight of the water turned the wheel. Modern water wheels, like the Pelton wheel shown in Fig. 7–19, use a fast-flowing stream of water, which hits buckets on the bottom of the wheel. This is sometimes called an *impulse* water wheel and obviously depends on a supply of water under high pressure.

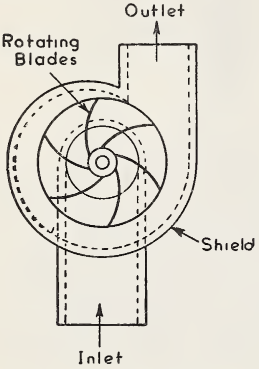
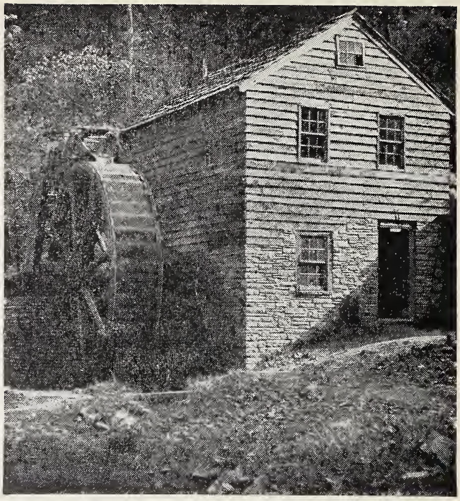


Fig. 7–17. A centrifugal pump.

Water Turbines. Modern hydroelectric plants often use the force of falling water to turn electric generators. Water from a river, for instance, first flows through a screen to remove floating debris. It then falls through large sloping tubes to the rim of a big wheel. Here it pushes against the vanes and rotates the wheel. The water is then carried into the center of the wheel, where it falls into the discharge tube or raceway below and returns to the river. Large water turbines may turn about 120 times a minute and drive electric generators set above them. The operation of the generators is described in Chapter 38.

WATER FOR TRANSPORTATION

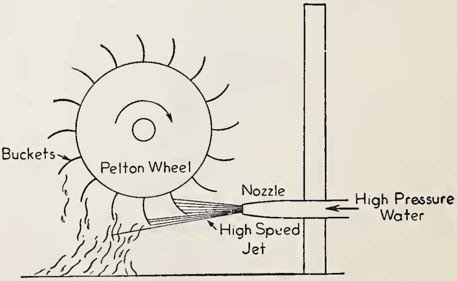
The oceans, lakes, and rivers of the world have for ages been lanes of travel and commerce for man. Boats, barges, ships, even rafts have carried goods and people long distances and spread civilization to all parts of the globe.



Ewing Galloway

Fig. 7–18. This water mill was built in 1798.

Buoyant Force. Why do ships float? Wood floats and steel sinks, yet boats can be made of wood or steel, or even cement. What holds them up? The answer to this question was discovered about 200 B.C. by a Greek scholar named Archimedes. History relates that while Archimedes was sitting in a bath he noticed that his arms felt lighter when they were un-



Central Scientific Co.

Fig. 7–19. High-speed Pelton water wheel.

der water, and that the more he submerged them the lighter they felt. He concluded that the water was exerting a lifting force upon his arms, and that this force depended upon the volume of his arms under water.

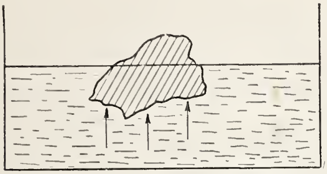


Fig. 7–20. A floating object protrudes through the surface of the water until the buoyant force of the water equals the weight of the object.

Water exerts a buoyant force on any object immersed in it. As Archimedes said, this force depends on the volume of the object under water. Though a stone seems lighter when under water than in air, it will sink because the buoyant force of the water is not equal to the weight of the stone. On the other hand, a piece of wood of the same size as the stone is acted upon by the same buoyant force when under water. Yet the buoyant force lifts the wood to the surface, where part of it protrudes as shown in Fig. 7–20. The wood floats with just enough of its volume under water to produce a buoyant force equal to the weight of the wood.

Fig. 7–21. Weighing a stone in air.

We can now see that if the piece of wood is hollowed out into a canoe, it will displace as much water as before, but that a load of people or baggage can now be placed in the canoe to replace the weight of the wood removed. The buoyant force of water therefore carries the load in the boat.

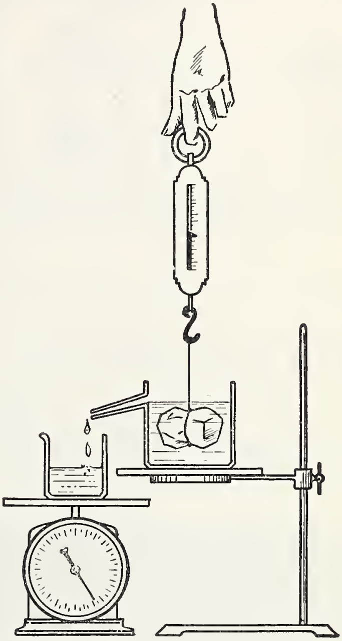


Fig. 7–22. Loss of weight of the stone equals weight of liquid displaced.

Steel ships float for the same reason, since the steel is only a shell that pushes the water aside. The inside of the steel shell is hollow and can be filled to some extent with power plant, cargo, and people.

A simple laboratory experiment will show

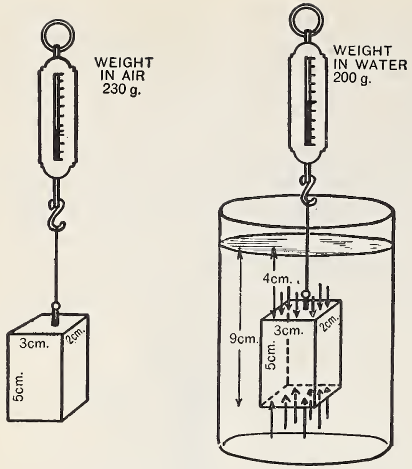


Fig. 7–23. Forces on a submerged object.

the nature of the buoyant force exerted by water.

Demonstration 7–6. Loss of Weight in Water.

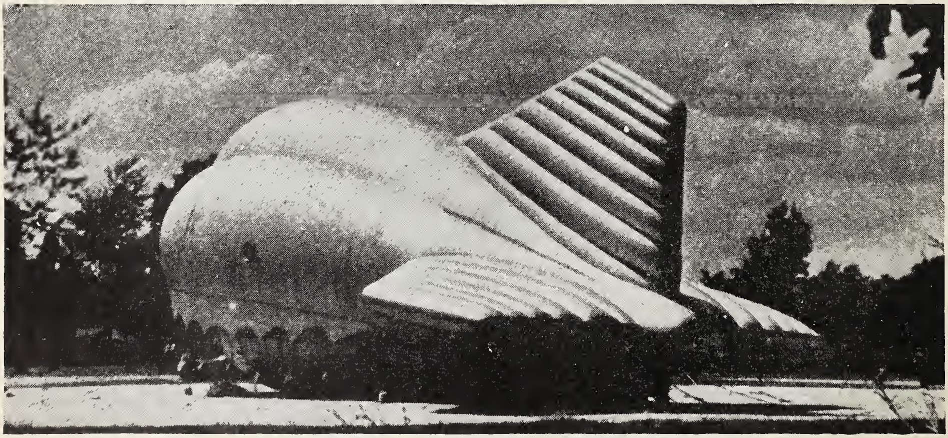
Suspend a stone from a spring balance as shown in Fig. 7–21, and record the weight of the stone. Now lower the stone into a vessel of water that is filled to overflowing. The stone will displace water, which we can catch and weigh as shown in Fig. 7–22. At the same time, we notice that the spring balance indicates a loss in the weight of the stone. Compare the difference between the two spring-balance readings of the weight of the stone with the weight of the water displaced by the stone. The two values should be the same. Why?

This experiment supports the general statement of Archimedes' Principle: *Any object immersed in a liquid is buoyed up by a force which equals the weight of the displaced liquid.*

From our knowledge of water pressure we can readily see that the bottom of an object immersed in water is subject to a greater force than the top. This is because the bottom is deeper in the water, where the pressure is greater. Fig. 7–23 shows these forces on a block immersed in water. The upward force equals the pressure on the bottom multiplied by the area of the bottom, or 54 grams, and the downward force is only 24 grams. Thus the buoyant force is 30 grams. Can you show that this equals the weight of the displaced water?

This explains why boats, even steel ones, can float on water and carry a load.

Balloons. In the same way, balloons and dirigibles displace air and are buoyed up by a



Courtesy U.S. Signal Corps

Fig. 7–24. This balloon will rise if its total weight is less than the weight of the displaced air.

force equal to the weight of the displaced air. If this force is as large as the weight of the balloon, the balloon will float. Small balloons, like those sold at fairs, are inflated with illuminating gas, which weighs less than air. Since the weight of the rubber and the gas inside it is less than the buoyant force, the balloon rises. Larger balloons are used to carry radio transmitters high into the atmosphere to record weather conditions. This is discussed in more detail in Chapter 20.

THINGS TO REMEMBER

Water exerts a *pressure* because of its *weight.*

Water exerts a *pressure in all directions,* and this pressure is the same in all directions at a given depth.

Water pressure *increases with depth* below the surface of the water.

U-tube manometers and *Bourdon gages* are used to measure pressures.

Pressure applied to a confined liquid is *transmitted without loss* to all parts of the container.

Mechanical advantage is *resistance* divided by *effort.*

Pressure in flowing liquids is reduced by friction.

Lift pumps and *force pumps* are commonly used to move liquids.

Objects immersed in a liquid are buoyed up by a force equal to the weight of the displaced liquid. This is called *Archimedes' Principle.*

QUESTIONS

A

1. How high must a column of water be to exert a pressure of 15 pounds per square inch on the bottom of its container?

2. What pressure is produced on its base by a column of water 64 feet high?

3. Why must the glass sides of a large aquarium be made of heavy glass?

4. Draw a cross section of a dam and explain why it has this shape.

5. A cider jug completely full of water is plugged loosely with a cork. What would happen if the cork were struck a sharp blow with a hammer? Explain.

6. How would you make a simple manometer to measure gas pressure?

7. Draw a simple diagram of the working parts of a Bourdon gage.

8. What pressure is exerted on the large piston of a hydraulic press if a pressure of 20 pounds per square inch is exerted on the small piston?

9. What is the mechanical advantage of a hydraulic lift pump in a service station if a force of 25 pounds will lift a car weighing 2 tons? 160

10. Why are small pipes poor economy in a town water-supply system?

11. How does a force pump differ from a centrifugal pump?

12. What do we mean by buoyant force? 2000 25

B

13. Draw a diagram of a pumping system in which water from a deep well is pumped into a storage tank in the attic of a farmhouse.

14. A hydraulic press has pistons whose areas are in the ratio of 10 to 1,000. What load can be lifted by a force of 10 pounds on the small piston?

15. How large is the buoyant force on an aluminum barrel that displaces 2 cubic feet of water when submerged? 2 cubic feet

16. Explain why steel ships can float.

PROJECT

To Determine Water-Pressure Variations. Obtain a pressure gage that can be connected directly to the water faucets in your school building. Measure the water pressure on each floor with nearby faucets closed, and again with these faucets open.

(*a*) Do the pressure readings decrease with height as they should? That is, does the pressure decrease in the ratio of 15 pounds per square inch for every 34 feet? Find out how far the faucet on the top floor is below the water surface in the standpipe of your town.

(*b*) Does the pressure change considerably when nearby faucets are opened?

(*c*) Is the water piping in your school building of a satisfactory size?

REVIEW QUESTIONS ON UNIT 1

A

1. What is meant by each of the following: (*a*) compound; (*b*) solution; (*c*) diffusion; (*d*) atomic weight; (*e*) solvent? Give an example of each.

2. What is the meaning of each of the following: (*a*) atom; (*b*) molecule; (*c*) atmosphere; (*d*) barometer?

3. What is: (*a*) the composition of air; (*b*) the composition of water; (*c*) the pressure of air?

4. Sea water is a solution. What does this mean?

5. Air is a mixture. What does this mean?

6. What is the purpose of chlorination in the preparation of drinking water?

7. Who were: (*a*) Archimedes; (*b*) Pascal?

8. Point out the errors in the following statements, giving a reason in each case:

- (*a*) An atom of sodium chloride is very small.
- (*b*) Gas pressure is caused by rapidly moving atoms.
- (*c*) A solution of chalk and water was poured into a beaker.
- (*d*) Air is 78 percent oxygen.
- (*e*) Pure distilled water is needed for drinking purposes.

B

9. State some of the industrial uses of water.

10. In what ways are solutions important?

11. Explain why a glass rod becomes charged with positive electricity when it is rubbed with silk.

12. Describe experiments to prove that a solid is more soluble in hot water than in cold water, and that a gas is less soluble. P. 26

13. What evidence is there that molecules of liquids and gases are in a state of motion?

14. Explain why the atmosphere has remained with the earth but not with the moon.

15. Explain the differences between a lift pump and a force pump.

16. (*a*) State Archimedes' Principle. (*b*) Explain why iron sinks and wood floats.

17. (*a*) What substances are recovered from sea water by animals and by man? (*b*) What are these substances used for?

18. Calculate the percentage of salt in sea water from the following data:

Wt. of evaporating dish = 125 grams
Wt. of dish and sea water = 425 grams
Wt. of dish and salt residue = 135 grams

19. (*a*) Describe an experiment to prove that air exerts a pressure. (*b*) State in two different units the amount of air pressure.

20. (*a*) Water and air have one constituent in common. What is it? (*b*) Can the constituent in air and water be used for the same purpose? (*c*) If not, why not?

21. Describe briefly the chemical tests by which you would recognize the gases: (*a*) carbon dioxide; (*b*) oxygen; (*c*) hydrogen.

SUGGESTIONS FOR FURTHER READING

A

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Unit 2

THE EARTH

8. THE EARTH AND ITS MOTIONS
9. ROCKS OF THE EARTH
10. THE CHANGING EARTH
11. THE RECORD OF ROCKS
12. LIFE IN EARTH HISTORY

Chapter 8

THE EARTH AND ITS MOTIONS

The Age of the Earth. Although the oceans are about 3½ percent salts (by weight), the sea is far from being saturated; indeed it can accommodate about ten times as much solid matter as it now holds. Yet it has taken millions of years to wash the present solids out of the land into the seas. How do we know this? Geologists can estimate fairly accurately the total amount of salts dissolved in the oceans. They also estimate that about 400,000,000 tons of solids are carried by rivers into the oceans every year. From the weights of these deposits geologists have calculated that the oceans must have existed for hundreds of millions of years.

Thus we know approximately how old the oceans are. Do we know how old the earth is? This will be discussed in some detail in Chapter 11. For the present we shall merely state that it is believed that the earth, like the other planets, was originally a hot gaseous mass torn away from the sun. As it cooled, it condensed to a molten, almost spherical body surrounded by a dense atmosphere of water vapor and air. On further cooling, a solid crust was formed on the earth, and the water vapor condensed to form the oceans. Therefore, according to this theory, the earliest seas were reservoirs of fresh water.

The age of the earliest crust can be found by examining some of its rocks, particularly the so-called *radioactive* rocks which contain elements like uranium. Uranium atoms disintegrate slowly at a constant rate. A lump of uranium changes one half of itself to lead every four and a half billion years. In other words, after 4,500,000,000 years, half a lump of uranium would become lead; after another 4,500,000,000 years one half of the remaining uranium would be changed to lead, and so on indefinitely. By finding the weights of the uranium and of the lead in a given rock, scientists can calculate how long this radioactive change has been going on; this, of course, gives the age of the rock.

By examining radioactive rocks from many different parts of the earth, scientists have concluded that *the solid earth was formed about two billion years ago.*

Let us now examine the earth a little more closely. What is its shape? Does it move in space?

The Earth Is a Sphere. When early man looked at the land about him, he saw nothing that suggested that the earth was a globe. To him the earth was flat and mountains were merely bulges on a plain. When he went to sea, however, the sight of new land might have surprised him. As he approached the land he would have seen first the highest peaks, then the foothills, and finally the beaches. Early man would have found it difficult to explain these observations if he believed that the earth was flat, but quite easy if he assumed that he was sailing over a curved surface.

By the 15th century a few men were not afraid to say they believed the earth was round.

Columbus was convinced that it was, and he proposed to prove it by sailing west to the Indies instead of east. The silks, spices, and other riches of the Indies were already well known to Europeans, but a journey to these islands required many weeks. To reach them, traders had to travel thousands of miles overland by caravan or else sail round the southern tip of Africa and through the Indian Ocean and the China Sea. In 1492 Columbus set out for the Indies by sailing across the ocean to the west. He reached a group of islands that he first thought were the Indies. Today these islands are called the West Indies, reminding us of Columbus' attempt to reach the East Indies by sailing westward to prove that the earth is round.

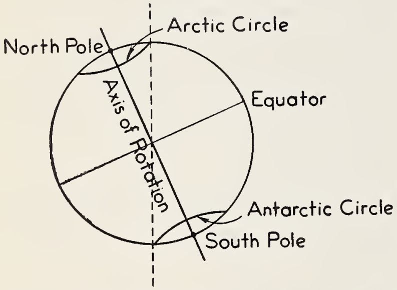


Fig. 8–1. The earth spins about an inclined axis of rotation.

A few years later a Portuguese named Magellan determined to sail completely around the world. He left Seville, Spain, in 1519. Although Magellan himself was killed, his battered expedition returned to Seville from the opposite direction in 1522. The voyages of Columbus and Magellan proved that the earth is round, not flat.

The Earth Spins. The sun appears to rise in the east, move across the sky from east to west, and set in the west. During the night it seems to return to its starting point, completing the cycle in 24 hours. This apparent motion of the sun does not, of course, prove that the sun really moves. We now know that the sun does not move and that its apparent motion is due to the rotation of the earth. The earth makes one complete rotation, or turn on its axis, every 24 hours. While half the earth's surface is illuminated by the sun's rays the other half is in darkness. *The rotation of the earth causes day and night.*

The first person to explain that the sun, not the earth, is the center of the solar system was Copernicus, a Polish astronomer. This was early in the 16th century, but only within the last three centuries have men come to accept Copernicus' idea.

The Four Seasons. The earth's axis is not straight up and down; it is tilted, or inclined. It always remains tilted in the same direction as it travels round the sun. If the axis were not tilted, there would be no difference in the lengths of the nights and days throughout the year, and there would be no difference between summer and winter. In other words, there would be no seasons.

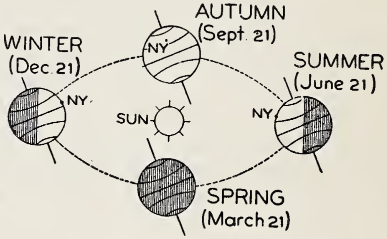


Fig. 8–2. The seasons.

The earth not only rotates on its axis once in 24 hours, but it also revolves around the sun in 365¼ days. The path along which the earth moves around the sun is called the orbit. The orbit is a slightly elongated circle, or an ellipse.

Let us see how the seasons and also the variation in the hours of sunlight are caused by the motion of the earth around the sun and the tilting of the axis. The diagram (Fig. 8–2) shows the positions of the earth in its orbit in spring, summer, autumn, and winter. (You can demonstrate this by using an apple to represent the earth, with a knitting needle through its core to represent the axis. Incline the axis slightly. Use a light bulb to represent the sun. Move the apple around the bulb in accordance with the above diagram.) In the diagram notice that in the position marked *Summer* the North Pole is *toward* the sun and the region of the North Pole remains in the light of the sun through the complete 24-hour rotation. During this period the region of the South Pole, on the other hand, is in complete darkness. When the earth is in this position all places north of the equator receive light for more than 12 hours, so that the days are longer than the nights. At the same time, in the Southern Hemisphere the nights are longer than the days; it is winter south of the equator.

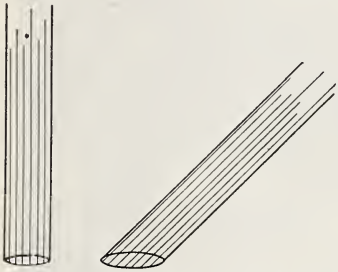


Fig. 8–3. The two beams have the same width and therefore convey the same amount of sun's heat. The heat in the vertical beam is concentrated in a smaller area than the heat in the slanted beam.

While the earth is in this position the sun is nearly vertical to places in the Northern Hemisphere. The rays of the sun that reach places in the Southern Hemisphere are slanted. Similarly, in the Northern Hemisphere the sun's rays slant more in winter than in summer. Fig. 8–3 shows one beam of sunlight that strikes the earth vertically and another that strikes it at an angle. The vertical beam forms a circular patch on the earth, whereas the slanting beam forms a larger oval or elliptical patch. (See Fig. 8–3.) The vertical rays concentrate the heat and light of the sun over the smaller area and, as a result, they heat the ground more than do the slanting rays. *It is this difference in the amount of heat and light received by the earth that causes winter and summer.*

Now let us turn to the position marked *Autumn* in Fig. 8–2. In this position the North Pole is tilted neither toward nor away from the sun; this is true also of the South Pole. Day and night are equal at all places on the earth; at the poles, at the equator, and at all places between, day and night are 12 hours long. This is the position of the autumn *equinox*. Its actual date is September 21.

In the position marked *Winter*, the North Pole is tilted away from the sun. As a result, the Northern Hemisphere receives less light and heat than does the Southern Hemisphere. Also, the sun's rays are more slanted in the north. This is the position of midwinter in the Northern Hemisphere.

The position marked *Spring* is similar to that marked *Autumn*. Neither the North Pole nor the South Pole tilts away from the sun. Thus the hemispheres receive equal amounts of light and heat. This is the position of the spring equinox, and the date is March 21.

From this we see that in the United States the sun's rays are most nearly vertical on June 21 and most inclined on December 21—these are the longest and shortest days, respectively. The hottest and coldest weather, however, comes after these dates, because the earth takes time to heat up in summer and to cool off in winter.

If the earth's axis were not inclined, there would still be differences in *climate* between different parts of the earth. The equator would still be very hot and the poles very cold. But there would be no seasons. This difference in climate would be due entirely to the difference in the slant of the sun's rays as they strike different parts of the earth. The inclined axis makes the differences in climate much greater by varying the length of night and day and by causing the seasons.

Latitude and Longitude. If we want to tell someone where the grocery store is, we can say, "At the corner of First and Main." If we want to explain where a certain farm is, we can say, "A mile and a quarter south of Jonesborough on Route 9." But if we want to explain where a forest ranger station is, or where a dam is to be built, or where a ship at sea is, there are no visible signposts. To locate such points we use *latitude* and *longitude.* Parallels of latitude are imaginary circles that run around the earth parallel to the equator. Meridians of longitude are imaginary circles that run around the earth through the North and South poles.

Latitude. Latitude is distance from the equator; it expresses distance north or south of the equator. The equator is an imaginary circle that passes around the earth midway between the poles dividing the surface into two equal parts. A circle that divides the earth into two equal parts is called a *great circle.*

Latitude is measured in degrees, not miles. The latitude of the equator is 0° and that of each pole is 90°. A *parallel of latitude* is an imaginary line around the earth all points on which are equidistant from the equator. All parallels of latitude are called *small circles* except the equator, which is the only great circle that is horizontal. Parallels become smaller circles as they approach the poles.

Parallels of latitude may be drawn any number of degrees apart; for example, 1°, 5°, 10°, 30°, 60°, and so on. One degree of latitude measures about 70 miles. It is found by dividing the circumference of the earth (24,800 miles) by 360. New York is almost on the 40th parallel of latitude in the Northern Hemisphere, or, as we say, 40° N. Its distance from the equator is therefore almost 2,800 miles.

Courtesy U.S. Weather Bureau

Fig. 8–4. Seasons are due to the tilting of the earth's axis. In the winter season the North Pole is tilted away from the sun.

When we want to be more exact, we express latitude in *degrees, minutes,* and *seconds;* 60 seconds make one minute, 60 minutes make one degree. The exact latitude of New York, using symbols, is 40° 45′ 06″ N.; of London, 51° 28′ 30″ N.; and of Capetown in South Africa, 33° 55′ 8″ S.

Longitude. Lines of longitude are great circles running north and south and passing through the North and South poles. They resemble the divisions of an orange. The equator can be divided into 360 degrees so that a line of longitude can be drawn through each of these points. These lines of longitude are farthest apart at the equator and they all converge at the poles. Places with the same *longitude* have the same *time*. For example, when it is midday in New York, it is also midday for all places directly north or south of it. For this reason lines of longitude are called *meridians*, from a Latin word meaning "middle of the day."

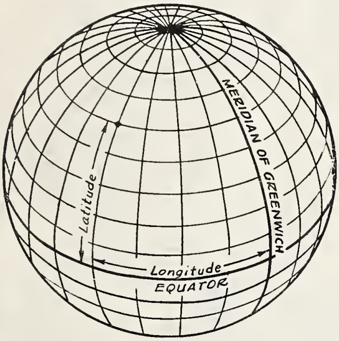


Fig. 8–5. Latitude and longitude. The position of the point on the sphere is latitude 50° N. and longitude 60° W. Notice that all lines of longitude are great circles, whereas the equator is the only line of latitude that is a great circle.

As the starting point for the measurement of longitude, practically all countries have adopted the Royal Observatory at Greenwich, London, England. Greenwich is considered 0°, and longitude is measured east and west from it through 180°. Places located on the 180th meridian are on the other half of the great circle that passes through Greenwich; that is, on the opposite side of the earth. Cities can thus be accurately located on the globe. For example,

New York	lat. 40°45′06″N.,	long. 73°59′39″W.
London	lat. 51°28′30″N.,	long. 0° 0′ 0″
Capetown	lat. 33°55′8″S.,	long. 18°25′35″E.

Time. By general agreement the day starts at midnight, or zero hour. The middle of the day is 12 hours or 12 o'clock noon (meridian); the hours between zero hour and twelve noon are referred to as A.M. (*ante meridiem*, "before noon"); between 12 noon and 12 midnight the hours are called P.M. (*post meridiem*, "after noon").

To avoid confusion, the 24 hour time-day is gradually being adopted. It is already used in many European countries, by astronomers, and by the armed forces. In this system all A.M. times are the same as our present A.M. times, but the P.M. times are expressed in numbers ranging from 13 to 24. For instance, 4 P.M. is 16 hours and 5:30 P.M. is 1730. In this system there is never any doubt as to whether the time referred to is morning or evening.

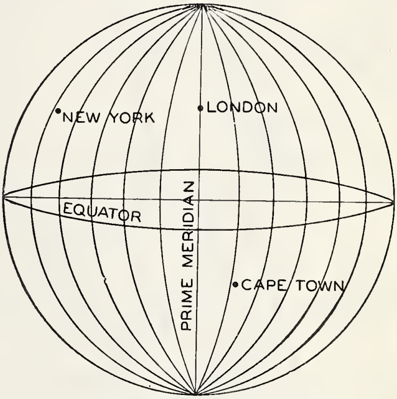


Fig. 8–6. Meridians of longitude.

Time Belts. When the sun is exactly overhead, or highest in the sky, the time is midday. Therefore each town or village really has its own midday, which is different from that of even nearby towns to the east or west. In the early days each town in the United States went by its own local time. The result was a great deal of confusion, especially when railroads tried to make up timetables. Watches had to be reset at every village. Since 1883, when standard time belts were established, all places in a given area or belt have the same time. Canada, which extends through about 88 degrees of longitude, has six time belts, each one about 15 degrees of longitude wide and differing by one hour from the belts on either side. (You will notice from Fig. 8–7 that there are actually seven, rather than six, different times in Canada—the seventh being Newfoundland Time, which is one half hour ahead of the time in Halifax. This is a special case as Newfoundland really is in the Atlantic Time Zone.)

If you leave the East Coast, say Halifax, and travel westward, you will find that your watch is ahead of the local clocks by one hour in Montreal, two hours in Winnipeg, three hours in Edmonton, four hours in Vancouver, and five hours in Whitehorse. In other words, in traveling from east to west you will have to set your watch back one hour every time you pass from one time belt into the next.

Each time belt represents a distance of $\frac{1}{24}$ of the earth's circumference of 360 degrees, that is, 15 degrees of longitude. The six zones in Canada are based on the mean sun time on the 60th, 75th, 90th, 105th, 120th, and 135th meridians, which are approximately the longitudes of Sydney, Montreal, Ft. William, Saskatoon, Kamloops, and Whitehorse. The lines indicating time belts are not always straight; they are slightly irregular to avoid giving two kinds of time to the same heavily populated region.

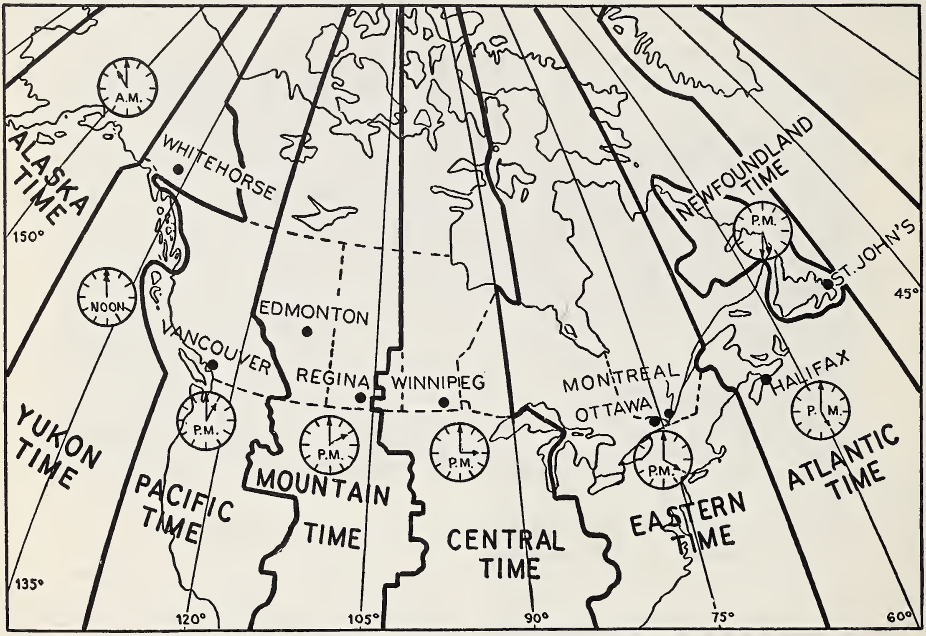


Fig. 8–7. Time belts in Canada and the United States.

International Date Line. Suppose that two ships set out from Greenwich, one traveling east and the other west. On the ship sailing east, clocks must be set an hour ahead for every 15 degrees of longitude traveled; that is, for every 15 degrees of longitude one hour is lost. On the ship sailing west, the opposite is true; clocks must be set back one hour for each 15 degrees and thus an hour is gained for every 15 degrees of longitude traveled.

What happens when the ships reach the 180th meridian? The ship sailing east will have lost 12 hours; for if Greenwich time is 6 P.M. *Wednesday,* ship's time will be 6 A.M. *Thursday.* On the other hand, the ship sailing west will have gained 12 hours, and its time will be 6 A.M. *Wednesday,* as shown in Fig. 8–8. By the calendar, therefore, just west of the 180th meridian it would be Thursday and just east of this meridian it would still be Wednesday. To overcome this difference, by international agreement the new day begins at the 180th meridian, and this meridian is therefore known as the *international date line.* On crossing the date line from the east a traveler moves his calendar ahead one day. On crossing from the west he repeats one day.

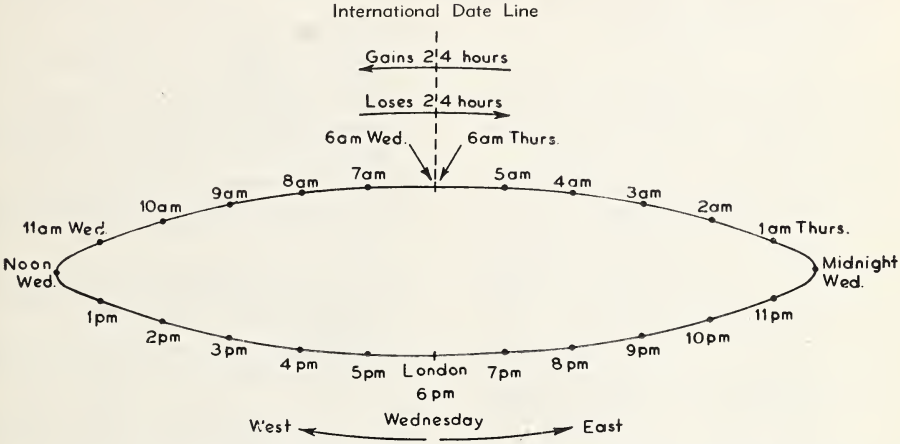


Fig. 8–8. Time zones on the parallel of latitude through Greenwich, London. Each time zone corresponds to 15° of longitude.

If you are sailing westward and happen to cross the 180th meridian about Wednesday midnight, the following morning is Friday; Thursday has disappeared. On the other hand, if you are sailing eastward and cross the date line about Wednesday midnight, the following morning is Wednesday. In other words, you have an extra Wednesday that week. What actually happens is that at the international date line you gain what you have lost in traveling eastward and lose what you have gained in traveling westward.

THINGS TO REMEMBER

The *earth* is probably about two billion years old.

The earth makes *one complete rotation* on its axis once every 24 hours.

Night and day are caused by the rotation of the earth.

The earth's axis is *inclined.*

The earth *revolves around the sun* in $365\frac{1}{4}$ days.

The *seasons* are caused by the tilting of the earth's axis and the motion of the earth around the sun.

The *spring equinox* is March 21, and the *fall equinox* is September 21.

Parallels of latitude indicate the position of a place north or south of the equator.

Meridians of longitude indicate the position of a place east or west of Greenwich, England.

There are *six time belts* in Canada; each differing from the belt on each side of it by one hour.

Longitude 180° is the *international date line.* On crossing this line, ships sailing east gain a day; those sailing west lose a day.

QUESTIONS

A

1. Determine which of the following statements are true and which are false. Then correctly reword the false ones.
- (*a*) The earth is about two million years old.
- (*b*) The spinning of the earth causes the seasons.
- (*c*) The earth's orbit is a perfect circle.
- (*d*) December 21 is a day of equinox.
- (*e*) If the earth's axis were not inclined, there would be no seasons.
- (*f*) All the parallels of latitude are small circles.
- (*g*) All the meridians of longitude are great circles.
- (*h*) The latitude of London is 0°.
- (*i*) There are six different time belts in Canada.
- (*j*) A time zone of 15 degrees of longitude corresponds to a time difference of one hour.

2. Explain the terms: (*a*) equinox; (*b*) meridian of longitude.

3. Explain how uranium ore is used to indicate the age of the earth.

B

4. In the month of June the days are longer than the nights in the Northern Hemisphere. Explain why.

5. In the month of June it is warmer in the Northern than in the Southern Hemisphere. Explain why.

6. Tell what latitude is and describe its use.

7. Establish the longitude and latitude of your present location. State precisely what this means.

8. A time zone is 15 degrees of longitude wide. How is this figure obtained, and what does it signify?

9. Explain what is meant by the international date line. Why is it necessary?

10. (*a*) State approximately the locations of the following places: (1) lat. 40° N., long. 75° W.; (2) lat. 0°, long. 30° W.; (3) lat. 89° S., long. 15° E.
(*b*) If it is noon at position (2), what is the time at positions (1) and (3)?

9:AM

PROJECT

Studying the Shadow Cast by the Sun. We can obtain considerable interesting information from the shadow of a pole made by the sun. On a piece of level ground set a straight stick or pole whose length you have measured.

On a bright day you can follow the path of the sun by placing a marker at the end of the shadow every hour. At the end of the day, measure the distances from the markers to the pole and also the angles between the lines running from the pole to the markers. These angles should be 15°. *Why?*

Notice that the direction of the shadow changes. In the morning it points west; in the evening it points east. What does this indicate?

Notice that the shadow is long in the morning and evening and shortest at noon. What does this indicate?

Draw to scale the length of the pole and the length of the shadow for such hours as 8 A.M., 10 A.M., 12 noon, 2 P.M., 4 P.M., and 6 P.M., Measure the angles of inclination of the sun's rays. What information do you get from these diagrams?

This experiment could be repeated at a different season so that you could observe the change that takes place in the direction of the sun's rays as the seasons change.

Chapter 9

ROCKS OF THE EARTH

Our planet, the earth, is made up of a numbers of layers, one inside the other. The outermost layer is the atmosphere. Next comes the water layer, which covers about three-quarters of the earth's surface. Then there is the crust of the earth which, here and there, juts through the water to form dry land.

Life on the earth is limited to a narrow zone near the surface that is probably not more than ten miles thick. Birds reach the upper limit; a few of them have been observed by explorers high up on the slopes of Mount Everest. On the other hand, living animals have been found in sea water at a depth of five miles or so. But these are the limits of the region of living things, and the total distance is only about $\frac{1}{800}$ of the diameter of the earth.

Nevertheless, both plant and animal life is varied within these narrow limits. The variation is due to several causes, one being the differences of climate. The flora and fauna (plants and animals) of the temperate zones differ from those of the tropics; and the flora and fauna of the tropics are quite unlike those of polar or desert regions.

But even in the same climatic zone plant and animal life vary considerably. This is true largely because of the different kinds of rocks on the surface. The earth's crust was formed by the cooling of molten rock. Why, then, are the rocks on the surface not the same everywhere? In order to answer this question, we must first consider the interior of the earth.

The Earth's Interior. There is no doubt that the interior of the earth is much hotter than the surface. Though it is impossible to take temperature readings at great depths, the readings taken in deep mines and in well borings, which may be 5,000 feet below the surface of the land, show that the deeper the bore the higher the temperature. Actually, the temperature rises about one degree centigrade for every one hundred feet of depth. At a depth of about three miles the rocks are at the same temperature as boiling water. The behavior of geysers is evidence to support this statement.

It is supposed that in the formation of a geyser surface waters seep through cracks in the crust and are heated by contact with the hot rocks below. The water boils, and the pressure of the steam throws out some of this hot water. Old Faithful, in Yellowstone National Park, Wyoming, is a familiar example of this process. See Fig. 9–1.

If we assume that the temperature increases with depth at the same rate, about 25 miles below the surface it will be high enough to melt rocks (about 2200° F.). Can we assume, therefore, that the rocks in the earth's interior are molten? It can be shown that the pressure exerted by overlying rocks at a depth of 25 miles is 20,000 times as great as the pressure of the atmosphere at the surface. This enormous pressure is enough to squeeze the rock molecules into a solid, probably a plastic solid. A plastic solid has the properties of both a liquid and a solid. It is hard and can be shattered if struck with a hammer; yet, if left on a sloping platform, it flows very slowly. Hard cobbler's wax and sealing wax are examples of plastic solids.

Rocks in the earth's interior behave like a plastic solid. They can flow, but very slowly. Since the heaviest material slowly sinks toward the center of the earth, there is reason to believe that the earth's center is made of metals, chiefly iron. It follows, then, that the earth itself is made up of layers—first a thin outer crust, then a deep layer of plastic rock, and below this an iron core that is much heavier than the rocky part of the earth. This three-layer earth is illustrated in Fig. 9–2.

Courtesy Northern Pacific Railway

Fig. 9–1. Old Faithful, the famous geyser in Yellowstone Park, ejects boiling water to an approximate height of 150 feet at hourly intervals.

Volcanoes. If a crack extends from the crust of the earth well into the interior, the pressure of the overlying rocks forces the hot plastic rock up and out. As the plastic rock rises, the pressure exerted on it diminishes so that eventually the rock melts and escapes from the crater as red-hot liquid lava. This forms a volcano.

Sometimes the lava wells out quietly from the opening at the top or on the side to build up an enormous cone. Mauna Loa in the Hawaiian Islands is a volcanic mountain. It rises 14,000 feet above sea level. The base of the cone is actually far below sea level, and Mauna Loa, measured from base to summit, is taller than Mount Everest.

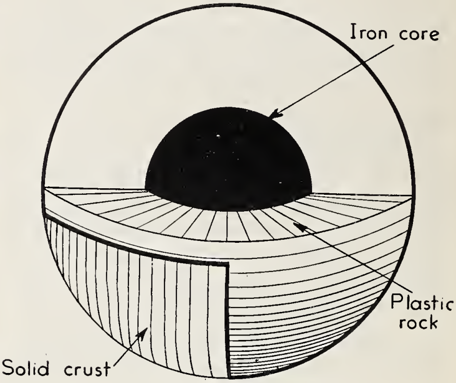
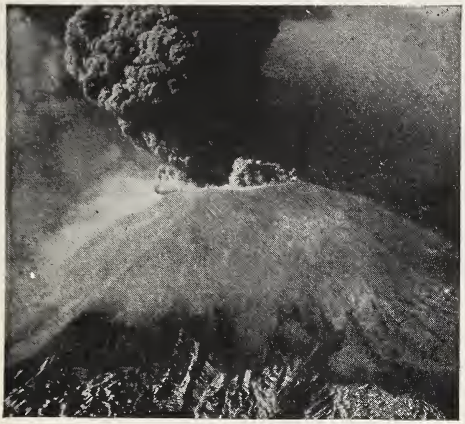


Fig. 9–2. The earth has a thin solid crust, a deep layer of plastic rock, and a core of iron and nickel.

Cones are not always formed, however. The lava may emerge through openings in the earth and spread over wide areas. Large parts of the state of Idaho, for example, are covered with lava formed in this way. Today there are no active volcanoes in Idaho, but millions of years ago large areas were covered by a sea of molten rock.

Sometimes a volcano explodes with great violence, scattering fragments of the cone, volcanic ash, and clouds of dust over vast areas. Mount Vesuvius is an explosive volcano. In the early days of the Christian Era, Vesuvius was a quiet, extinct volcano. The soil at its base was fertile, and the towns of Herculaneum and Pompeii grew and thrived in this pleasant land. Then in the year 63 there was a violent earthquake in this region, and in the year 79 Vesuvius burst into violent activity. Ashes and dust were strewn miles around. Herculaneum and Pompeii were completely buried for many centuries. Only within the last century has the debris been removed to expose the ancient cities.



Courtesy U.S. Army A.A.F.

Fig. 9–3. Mount Vesuvius in eruption. This photograph was taken during a bombing expedition in World War II.

Volcanic Rocks. Molten lava cools rapidly in air. The rate of cooling determines the structure of the rock. Do you remember the cooling of a saturated solution of potassium nitrate described on page 26? If the solution is cooled rapidly, the molecules of potassium nitrate do not have time to align themselves to form big crystals. The result is that only minute crystals are formed. But if the saturated solution is cooled slowly, the molecules can align themselves to form a large structure, and crystals an inch long can be grown in this way. This also happens in the cooling of rock material. If the molten rock cools rapidly, the crystals may be too minute to be seen; if it cools slowly, crystals large enough to be seen by the naked eye are formed.

Molten rock under pressure contains gases, which escape as the lava cools. If the lava hardens before the gas bubbles have escaped, a porous rock called *pumice* is formed. Usually, however, the lava forms a noncrystalline rock called *basalt*. Sometimes it cools so rapidly that it looks like glass. Glass itself is a noncrystalline substance. One of the black lavas, *obsidian*, looks very much like bottle glass.

Intrusions. If the crack in the crust does not extend all the way to the surface, the molten rock spreads out to form horizontal deposits called *intrusions*, as shown in Fig. 9–4. As the lava accumulates, the overlying beds are pushed upward, so that even mountains may be formed in this way. These large intruded masses of molten rock, which may lie far below the surface, cool very slowly, probably through a million years or so. There is ample time for the rock crystals to grow to a considerable size, sometimes to more than an inch in length. Granite is a rock of this type. If you examine a piece of granite, you will notice that it contains three kinds of crystals: *feldspar*, which may be gray or red; *quartz*, which looks like glass; and probably *mica*, which forms little black or white plates.

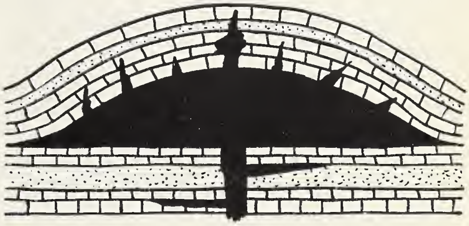
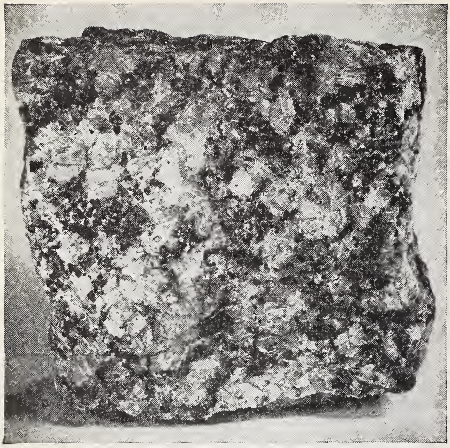


Fig. 9–4. An intrusion. Molten lava has forced its way between the horizontal deposits and has arched the overlying beds to form a dome.

Wherever granite appears on the surface of



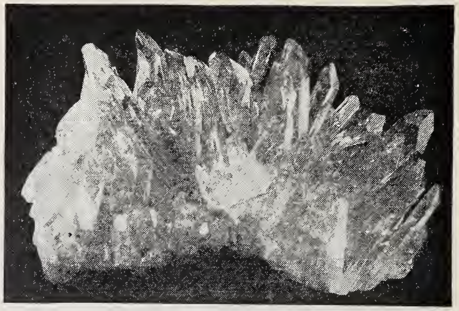
Ward's Natural Science Establishment, Inc.

Fig. 9–5. Granite.

the earth, we know that the rocks which at one time covered it have been worn away by a process called weathering. This process is discussed in the next chapter. Granite is a hard rock that resists weathering. It is therefore often used as building stone. Because of the massive outcrops of granite in the White Mountains, New Hampshire is aptly called the "Granite State."

Granite and lava are igneous rocks; that is, they were originally molten. The word *igneous,* like *ignite,* comes from a Latin word meaning "fire." There are many kinds of igneous rocks. They make up more than 90 percent of the earth's crust.

Sedimentary Rocks. When, in the beginning, the crust of the earth became thick enough to prevent internal heat from reaching the surface, the atmosphere cooled and water vapor began to condense. The atmosphere was so heavily charged with water vapor that rain fell in torrents. The water collected in depressions in the earth's crust and formed rivers and seas. The rain and the rivers gradually wore away the land, carrying loosened particles to the sea, where they were deposited as sediment. This sediment formed the first *sedimentary rocks.*



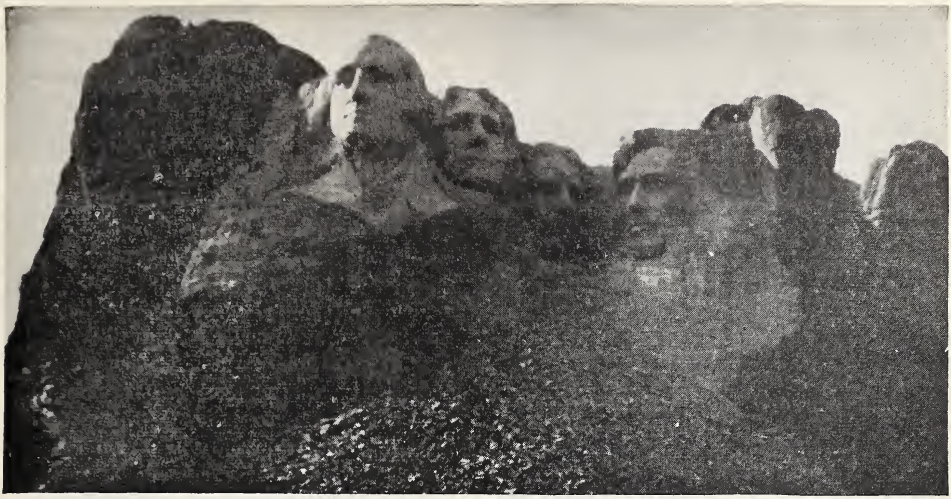
American Museum of Natural History

Fig. 9–6. Quartz crystals.

Sedimentary rocks, as the name suggests, are rocks formed, for the most part, from deposits of sediment in water. Probably you have noticed that streams are muddy after a rainstorm. So long as the stream is flowing it can carry the mud, but when it reaches a pond its movement is checked and the mud sinks to the bottom. On a larger scale, when a river reaches the sea, it is slowed down, and the material suspended in it falls to the sea floor. The heaviest material falls first, forming beds of pebbles and gravel. Lighter material, such as sand, is carried farther out to sea before being deposited, and the finest particles of all are carried to great distances before they settle to form mud.

In the course of time these deposits are compressed and cemented together to form rock. The cement usually consists of various minerals that bind the grains together. It may be fairly easily dissolved or broken, and for this reason sedimentary rocks are commonly soft and disintegrate readily.

Sedimentary rocks are usually classified according to the size of the fragments of which they are made. Thus cemented pebbles and gravel form *conglomerate;* cemented sand forms *sandstone;* hardened mud or clay forms *shale. Glacial till* is an exception in this classi-



Courtesy Ethyl Corp.

Fig. 9–7. Mount Rushmore Memorial, Black Hills, South Dakota. The figures of four of our greatest presidents—Washington, Jefferson, Lincoln, and Theodore Roosevelt—are carved out of hard granite. The carving of the figures took 15 years to complete; during this time about 400,000 tons of granite were hewn out of the mountain. The head of each figure is 60 feet high.

Rain, frost, and wind will gradually wear away the memorial. But geologists have estimated that the extent of erosion will not be more than 1/16 inch per century, so it will last for thousands of years.

fication because, as we shall see in the next chapter, it consists of a variety of deposits laid down by glaciers.

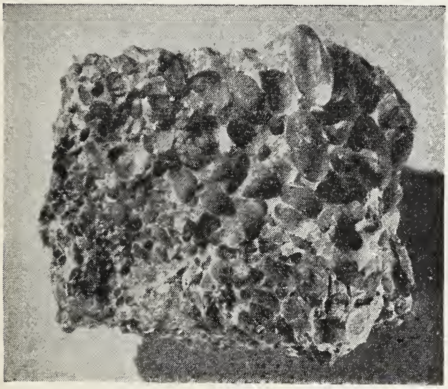


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Fig. 9–8. Conglomerate.

Limestone and Chalk. Another type of sedimentary rock is formed by the deposit of substances in solution, chiefly through the aid of animals. Calcium carbonate is an example. Many shellfish extract calcium carbonate from sea water to build up their hard shells. When these fish die, the hard parts accumulate on the sea floor to form *limestone* deposits, sometimes hundreds of feet thick. In the course of time the rocks may be raised above sea level by earth movement. They then form a limestone ridge or mountain. The structures of these shellfish can sometimes be seen in limestone.

Limestone is not always formed from the shells of animals, however. Much of the calcium carbonate in sea water is simply deposited as the result of a chemical action. Such limestone shows no trace of shell structure.

Still farther out at sea, far beyond the region of the mud and the shellfish, the sea floor is covered with other deposits which are chiefly the remains of organisms that live in the sea. *Globigerina* are an example. They are usually microscopic in size, yet they may leave deposits thick enough to form mountains. Globigerina are tiny floating creatures with skeletons of lime or calcium carbonate. Fig. 9–9 shows a glass model of Globigerina greatly enlarged. Notice the long spines. Through them the living animal took in food. Actually a Globigerina skeleton usually consists of several minute spherical shells, as shown in Fig. 9–10. When the animal dies, the spines break off and the shells accumulate to form the rock called *chalk*. The Globigerina shown in the picture are part of a deep-sea deposit. They were magnified about twenty-five times when photographed.

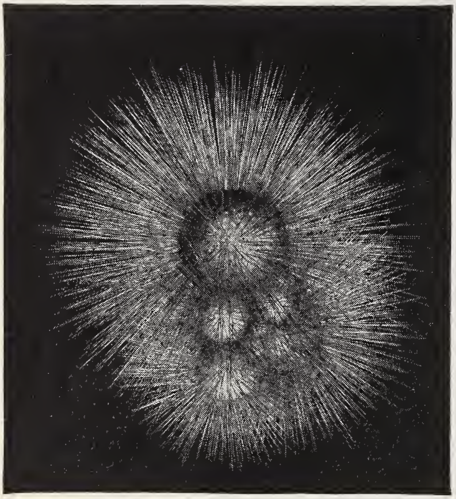

American Museum of Natural History

Fig. 9–9. Globigerina, a glass model by Herman Mueller.

Chalk therefore has the same chemical composition as limestone. But since chalk was formed in much deeper water than limestone, it is free from the particles of sand and mud often found in limestone.

Thick deposits, such as coral, can also be formed from the remains of animals that live on the floor of the sea. Corals are animals that live in shallow water, and hundreds of them grow from a central rocky stem. When they die, the hard parts pile up on the ocean floor, and other corals live and grow on the skeletons below. In this way coral deposits of great thickness are formed. Indeed, whole islands, such as Bermuda in the Atlantic and Wake in the Pacific, are formed of coral deposits.

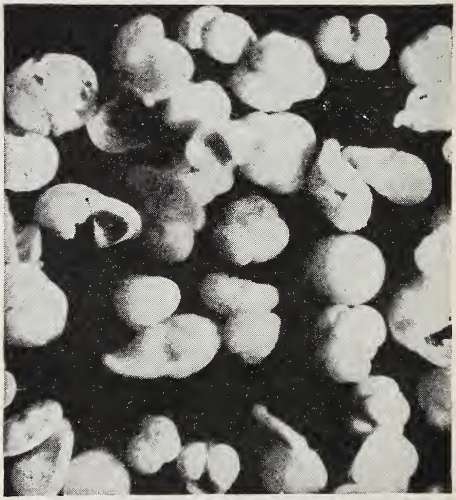
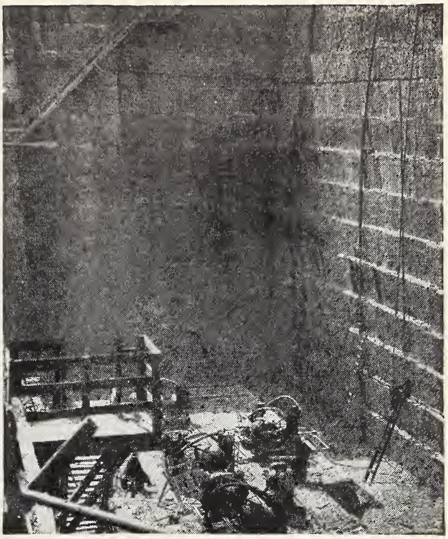


Fig. 9–10. Globigerina shells magnified 25 times.

From sedimentary rocks the geologist learns a great deal about the history of the earth. This will be discussed in Chapters 11 and 12.

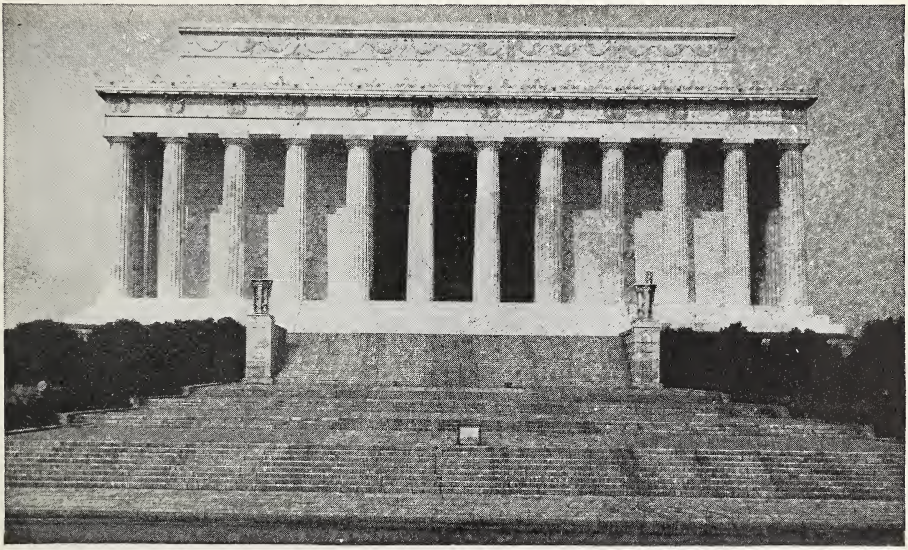
Metamorphic Rocks. Sedimentary deposits have been laid down ever since the earliest streams carried material into the fresh-water seas, and these deposits are still being laid down. Sedimentary rocks are formed in layers, which, through the ages, may change in nature. We may find, for example, a bed of sandstone resting on shale, and this, in turn, resting on limestone. But another type of change, one that alters the nature of the rock entirely, may take place.

Marble. Let us see what would happen if a mass of molten lava, for instance, were injected into layers of limestone or chalk. Some of the limestone would react chemically with the lava to form new compounds, and some of it would simply be melted by the heat of the intruded rock. As the melted limestone or chalk cooled, it would crystallize, but the new crystal structure would be quite different from that of limestone or chalk. All traces of shell structure would disappear, and the rock would look more like an igneous rock than like a sedimentary rock. Rock formed in this way is *marble.* Marble has the same chemical composition as limestone or chalk; it is calcium carbonate. It is harder, however, and very different in appearance. It is a *metamorphic* rock. The word *metamorphic* means "changed in form."



Courtesy Vermont Marble Co.

Fig. 9–11. A marble quarry several hundred feet deep.



Courtesy U.S. National Park Service

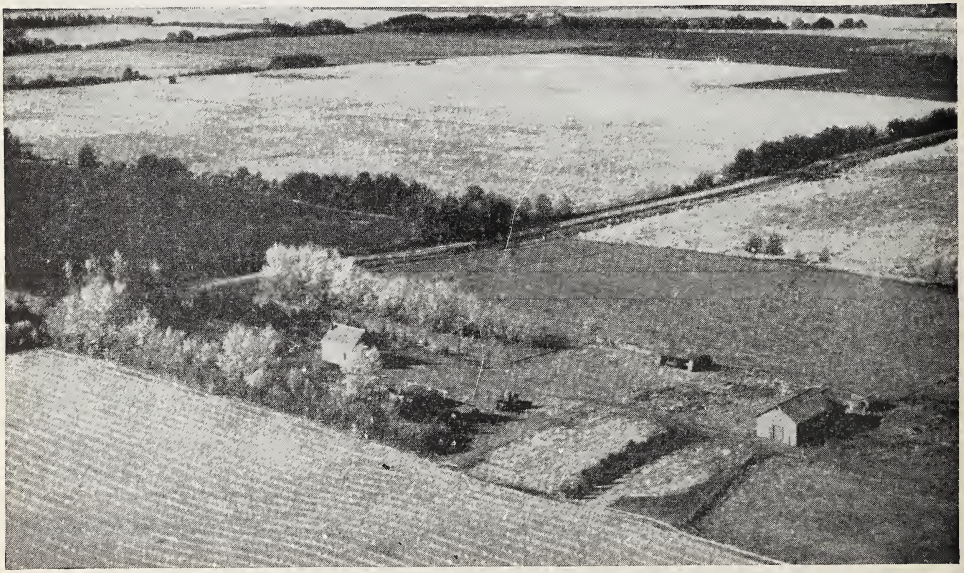
Fig. 9–12. The Lincoln Memorial. Marble can be carved and polished and is therefore used widely as a building stone.

Slate. Shale also may be changed, or metamorphosed, by pressure. The particles turn their flat faces in the direction of the pressure, and the shale is compressed, altered in chemical composition, and hardened at the same time. In this way *slate* is formed. Because of this change in structure, slate can be split into thin slabs. For this reason it is used as roofing material. Many other rocks, even igneous rocks, also undergo metamorphism. Granite, for example, may be changed into a banded rock called *gneiss.* Metamorphic rocks constitute the third and last group in the classification of rocks: (*a*) *igneous,* (*b*) *sedimentary,* and (*c*) *metamorphic.*

The Physical Features of Canada. If we travel by airplane from the east to the west coast of Canada at about latitude 50° N., we see many of the main physical features of our country. Over Newfoundland we see the Canadian Shield for the first time. Then, crossing the Strait of Belle Isle and the Gulf of St. Lawrence, we see the Laurentian Mountains rising from the Lowlands bordering the Gulf. The Laurentians are really part of the Canadian Shield, which stretches from Quebec across Ontario, into Manitoba, and northwestward to Great Slave and Great Bear Lakes. The bedrocks underlying this plateau are igneous and metamorphic and on top are some sedimentary types. On a portion of the Shield, in Northern Ontario, lies the Great Clay Belt.

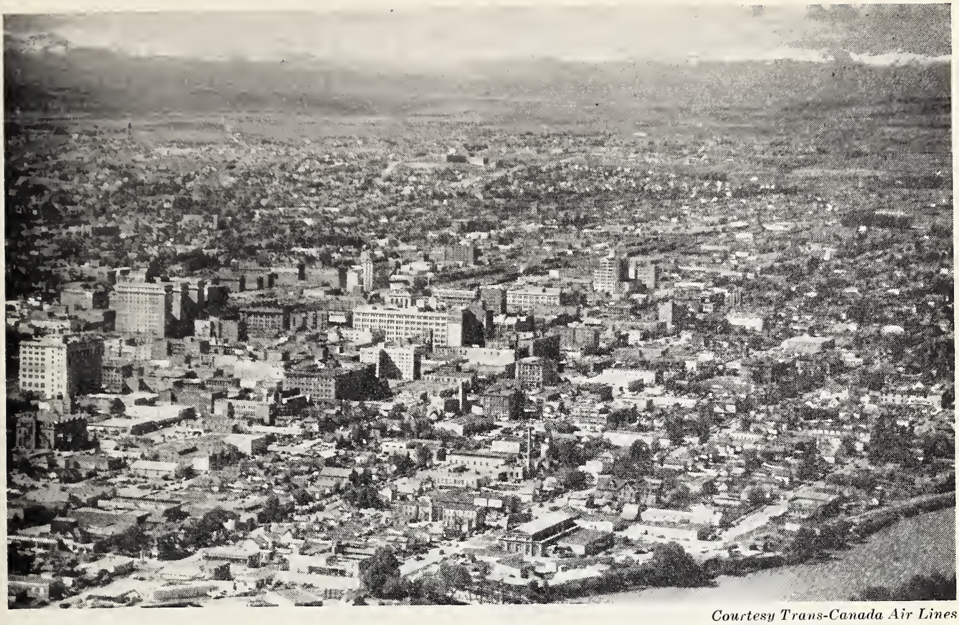
As we travel westward we notice that the nature of the land changes in Manitoba and realize that we are coming upon the Great Plains which extend westward to the Rocky Mountains. These plains are covered by a rich soil; here is the granary of Canada. If we could look under this soil, we should find belts of sedimentary rock and tertiary gravel.

Soon we see the Rocky Mountains towering ahead of us, and we cross their lofty rugged peaks into British Columbia. West of the mountains we get the impression of mountain ranges but actually we are flying over a plat-



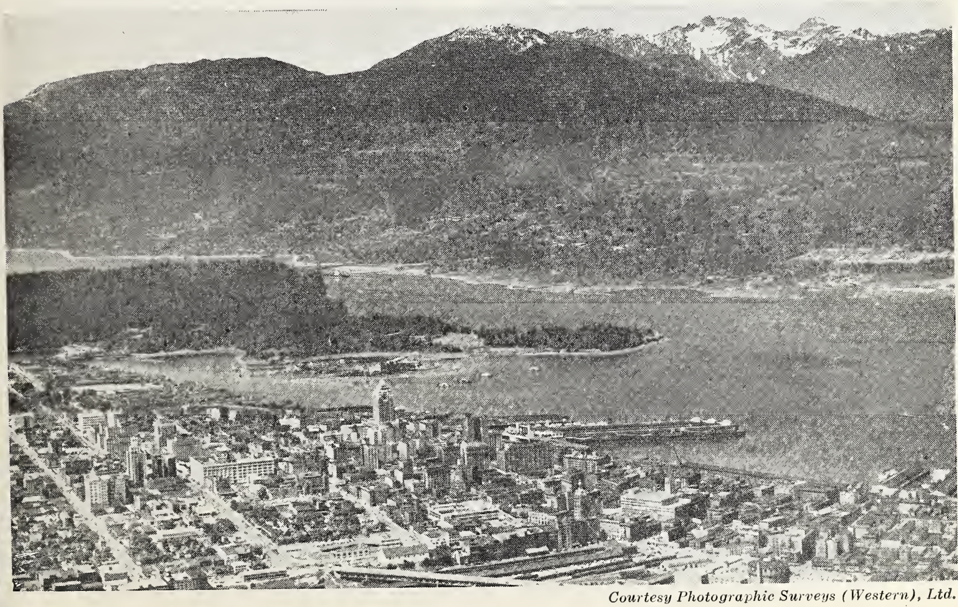
Courtesy Airview Photos

Fig. 9–13. Rich "black soil" area near Red Deer, Alberta.



Courtesy Trans-Canada Air Lines

Fig. 9–14. The city of Calgary, and the approoch to the Rockies.



Courtesy Photographic Surveys (Western), Ltd.

Fig 9–15. Vancouver, with port of the coost range in the bockground.

eau deeply entrenched and eroded. Further west, in the Okanagan Region, the impression of a plateau is more clearly-cut. Here the rocks are a complex of igneous, metamorphic and sedimentary. When we reach the Pacific Coast we again meet the granite peaks of the Coastal Range.

Geologically this has been an exciting trip, and one could ask many questions about our journey. Why do the mountains run north and south for the most part? Why do we find rugged peaks when the rocks are hard like granite, and rounded ridges when the rocks are soft like shale? Why do we find sedimentary rocks in the Prairies and igneous and metamorphic rock in the Rocky Mountains?

If we knew the geologic history of Canada, we could answer all these questions. We shall, however, make an effort to answer some of them in the next chapter.

THINGS TO REMEMBER

The *earth's interior* is hot enough to melt rocks at a depth of about twenty-five miles.

The solid earth consists of *three zones:* (*a*) a thin outer crust, (*b*) a thick layer of plastic rock, and (*c*) a core of iron.

Lava is a volcanic rock.

Igneous rocks were once molten. Examples are basalt and granite.

Sedimentary rocks are usually deposited in water. Examples are limestone, shale, and sandstone.

Chalk and some *limestone* are formed from the shells of sea animals.

Metamorphic rocks are rocks that have been changed by heat and pressure. Examples are marble and slate.

QUESTIONS

A

1. Determine which of the following statements are true and which are false. Then correctly reword the false ones.
   (*a*) Volcanoes prove that the interior of the earth contains molten rock.
   (*b*) Chalk is a sedimentary rock.
   (*c*) Marble is an igneous rock.
   (*d*) Globigerina are microscopic animals that live near the surface of the sea.
   (*e*) Slate is formed from shale by metamorphism.
   (*f*) An igneous rock is made by fire.

2. What causes the holes in pumice?

3. What is: (*a*) an igneous rock; (*b*) a sedimentary rock; (*c*) a metamorphic rock? Give an example of each.

4. State whether each of the following rocks is igneous, sedimentary, or metamorphic: (*a*) obsidian; (*b*) slate; (*c*) gneiss; (*d*) limestone; (*e*) marble; (*f*) granite; (*g*) shale.

B

5. Explain how a geyser is formed.

6. Explain how granite may be formed.

7. Explain how chalk may be converted into marble.

8. State the main physical features of Canada that you would encounter if you were to fly from east to west at approximately latitude 50° N.

9. (*a*) How would you distinguish a piece of granite from a piece of sandstone?
   (*b*) Explain how each of these rocks was formed.

PROJECT

Collecting Rocks. If you are interested in geology, you should collect rock specimens. Obtain different rocks and minerals, boulders scratched by glaciers, rocks that show intrusions or folds. Identify and label each specimen and record the location of each find. Catalogue and store the specimens.

Chapter 10

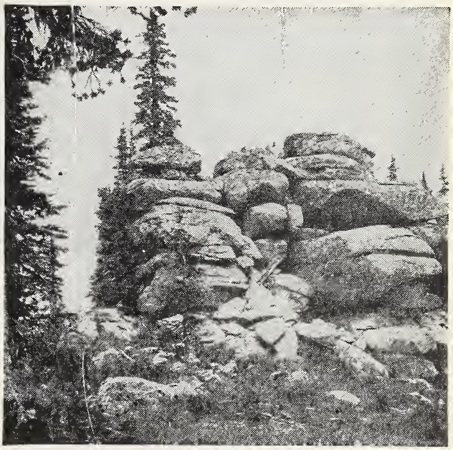
THE CHANGING EARTH

The slow cooling of the plastic interior of the earth has continued ever since the crust was first formed. The temperature of the interior is probably as high as it was originally, and the cooling effect has probably not extended more than a few hundred miles. Nevertheless, cooling causes contraction and, as a result, the crust is continuously getting too large for the layer below. This sets up great strains in the plastic interior, so that some rock is pushed up through the crust. Some geologists believe this rock movement may account for the formation of mountains.

If we ask what causes mountains, we are on controversial ground. Scientists disagree on the answer. The forces that raise mountains are not fully understood, and geologists have several theories, in addition to the cooling interior, that try to explain them. All are agreed, however, that the rocks in the interior are under great stress and that the slow elevation of mountains is a motion that relieves the stress. We shall therefore leave the question unanswered and turn to another upon which we have much more direct evidence: What causes mountains to wear away or disintegrate?

There is plenty of evidence to show that some parts of the earth are being slowly elevated. But this process does not go on unhindered, for exposed rocks are attacked in a variety of ways—by rivers, by seas, by winds, by glaciers—all of which tend to wear them down. This wearing-away of rock surfaces and the removal of the loosened material is called *erosion.*

The weather is responsible for considerable erosion. Not only storms and floods but also the day-to-day wind, rain, and sun cause changes on the earth's surface. In fact, weathering is one of the main factors of erosion. Winds, for example, may pick up dust and sand and carry them great distances, often hundreds of miles. The amount of dust in the air may be very great. It has been estimated that in a violent dust storm one cubic mile of air may contain more than 100,000 tons of dust and sand.



Courtesy U.S. Geological Survey

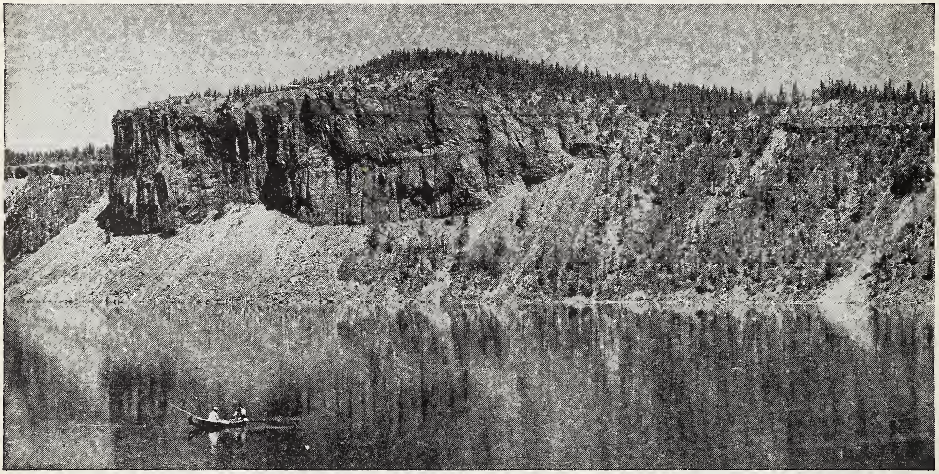
Fig. 10—1. Weathered granite.

Wind-blown sand cuts and wears the rock surfaces in much the same way as a sandblast etches glass and other hard substances. Wind erosion is most effective in dry regions, because surface rocks are often bare and unprotected by vegetation. A desert region, for instance, is largely the result of wind erosion. Exposed rocks are eroded by the driven sand until eventually they are destroyed and a nearly level plain covered by gravel and sand is formed.

Erosion by Heat and Cold. When exposed rock surfaces are heated by the sun's rays, they expand. But heat does not travel readily in rock, so that the under layers receive little heat and do not expand. Internal strains due to the expansion of the surface layers cause the rocks to break off. As new rock surfaces are exposed, the expansion continues, and the shelling-off of the outer layer proceeds indefinitely.

Water often seeps into the pores of rocks and rock crevices. As the water freezes it expands. The force of expansion is great enough to split rocks apart, and the continued freezing and thawing process may tear great chunks of rock away from the main rock mass.

Even tree roots, which, in growing, enter into small rock fissures, may exert enough force to displace slabs of rock. If the exposed rock is a cliff or steep mountain side, the loosened fragments will slide to the base and collect there. Such a pile of debris is called *talus*. Through the years the accumulations may be great enough to bury whole mountain sides.



Courtesy U.S. Geological Survey

Fig. 10–2. Notice the accumulation of talus at the base of the cliff.

Even the hardest rocks can be weathered. There is evidence of weathering all around us. For example, as the years go by, inscriptions on old buildings, monuments, and tombstones fade and eventually become almost illegible. If the carved lettering dates back to 1850, there are obvious signs of wear; if it dates back to 1750, it may be difficult to read. In the course of two hundred years the whole rock slab may be worn away to a depth of a quarter inch or even half inch. If so great a change takes place within the short space of two hundred years, what must be the total effect on exposed rock surfaces over a period of millions of years?

Erosion by Running Water. Running water is an even more effective eroding agent than wind. The source of all river water is, of course, the rain that falls on the land. The annual rainfall varies greatly from place to place. In the Nevada desert, for example, it is about 4 inches; in Chicago, about 30 inches; in New York, about 40 inches; in New Orleans, about 60 inches; and on the southern slopes of the Himalayas, about 100 inches. Some of this water evaporates, some sinks into the ground, and some runs down the surface slopes as rainwash.

The rain that soaks into the ground collects in the spaces between the soil particles. With more rain, the subsoil becomes saturated; the water begins to flow, and eventually it emerges as a streamlet. The water also helps to break up the rocks by dissolving parts of them. This dissolving action is considerably greater when the water has carbon dioxide dissolved in it (see page 94). The removal of the soluble parts makes the rocks more porous and also weakens their structure so that they crumble more easily. Sandstone crumbles to sand, and conglomerate to gravel. As a result, rainwash is able to erode the land. For example, water running off a plowed field carries many particles of mud or sand.

But let us return to the emerging streamlet. On the surface it is joined by other streamlets so that it grows until it is big enough to sweep along fine particles of soil. In this way the stream begins to carve a little trough in the land, which becomes larger as more small streams join the main stream. Eventually the trough may become a gully, such as we often see on the side of a hill.

The stream is now big and fast enough to carry along particles of different sizes. The lighter materials, such as mud and silt, are suspended in the water, but heavier materials, like sand and pebbles, are rolled along the bed of the stream. As these larger particles are swept along, they act like sandpaper and wear the bed and banks of the stream. Even the hardest rock is worn in this way, so that a river gradually deepens and widens its bed. Rain and frost also wear away the banks of a river, and as a result loose material is continually falling into the stream.

It should be observed that erosion by running water produces two different effects: (1) the deepening and widening of the river and (2) a general lowering of the land in the whole river basin. Geologists have estimated that rivers carry 5,000,000,000 tons of mineral matter in solution into the sea every year. And the amount carried down as sediment is much greater. Erosion by running water lowers the land masses of whole continents.

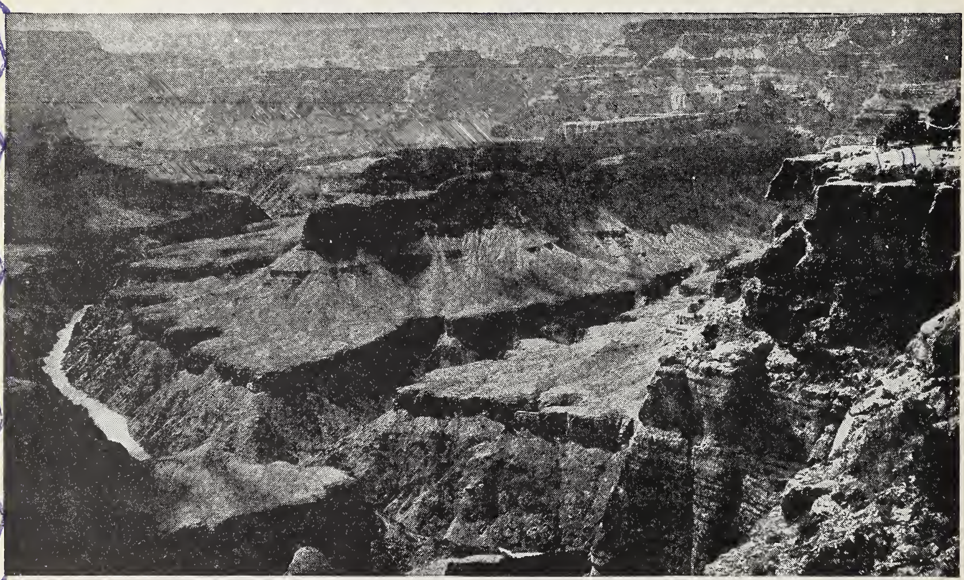
The Mississippi. The central midwestern plain from Ohio to Colorado is drained by the Mississippi River and its tributaries. Through the centuries the rivers have worn down the entire region so that it is almost completely level. Geologists have calculated that this *plain of erosion,* the work of the Mississippi, has been in the process of formation for millions of years.

At the present time the Mississippi Basin is being lowered at the rate of one foot in about five thousand years. If all the continents were worn down at this rate and if there were no forces to offset the erosion of rivers, all land areas on the earth would be destroyed. Fortunately, however, as was pointed out at the beginning of the chapter, other forces raise land areas above sea level.

The muddiness of the Mississippi is proverbial. Mark Twain is supposed to have said of the Mississippi River, "It is too thick to navigate but too thin to cultivate." The sediment carried by the Mississippi amounts to more than 500,000,000 tons a year. This enormous load, which is stolen mostly from the fertile lands of Ohio, accumulates as a fan-shaped deposit in the Gulf of Mexico near the mouth of the river. Such a deposit is called a *delta* because it resembles the Greek letter delta, which is written Δ. The Mississippi Delta, one of the largest deltas in the world, has already extended about a hundred miles into the Gulf of Mexico.

The lower Mississippi Basin is wide and flat. During the spring floods the river frequently overflows its banks. When the flooding waters meet the land, they are slowed down and drop much of their load. The sediment that is deposited forms broad ridges of earth, or natural *levees,* along the banks of the river. To keep the river within its channel and thus prevent flooding, engineers have enlarged these natural levees. In spite of these precautions, however, disastrous floods still occur in the Mississippi Valley. However, a government flood-control project is now under way and dams are being constructed on the tributaries of the Mississippi to supply water for irrigation in the dry regions and to protect the lower regions against floods. The dams will also be used to generate electricity for future industries.

The Colorado River. There is no better example of river erosion than that of the Colorado River, which rises in the Rockies and flows through Arizona, Nevada, and southern California. When the snow melts in the Rockies, the Colorado becomes a rapid, treacherous river, and it has caused many dangerous floods.



Courtesy U.S. National Park Service

Fig. 10–3. The Grand Canyon. Notice the narrow Colorado River at the bottom of the wide canyon.

In northern Arizona the swiftly flowing river has carved a deep canyon out of solid rock. The Grand Canyon is a gigantic trough about 200 miles long, varying in width from 4 to 18 miles. The river runs in a narrow gorge more than a mile deep. In the gorge are dozens of peaks that are taller than any mountain east of the Rockies yet their crests are below the rim of the canyon.

By studying the Grand Canyon, geologists

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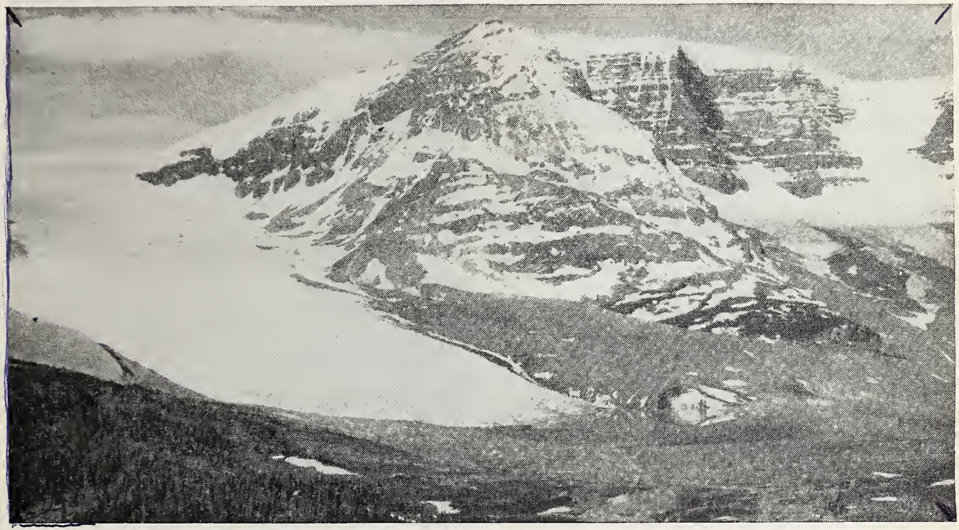
have traced the geological history of the Colorado Basin. For millions of years the region was covered by sea. During this time the sandstones, limestones, and shales were being deposited. Later these sedimentary rocks were raised above sea level, and the Colorado River then began its life as a mountain stream flowing from the Rockies to the Gulf of California. In making the canyon, the river first cut its way through about 4,000 feet of sedimentary rocks consisting of red sandstone, white limestone, and gray-blue shale. Then it carved a gorge about 1,000 feet deep in the igneous rocks that lie below the shale. The Colorado River flows through some very dry regions that must be irrigated in order to make the land fertile. At a number of places along its course dams, such as the Hoover Dam, have been built to hold back the waters in times of flood and to store them for irrigation.



Courtesy Alberta Government

Fig. 10–4. Athabaska Glacier and Columbia Ice Fields.

Glaciers. In some regions of the earth not all the snow that falls during the winter melts during the following summer. These regions are covered by perpetual snow. The upper layers of snow compress the lower layers into ice, and at the same time force some of the ice to flow to a lower level. This river of ice is called a *glacier*.

As a glacier moves slowly down a mountain, it gouges rock fragments out of the sides. The fragments may fall to the bottom of the glacier and become frozen there; they scratch and wear the floor and sides of the valley as the glacier moves along. The sand, pebbles, and boulders that result from this abrasion also move along with the glacier.

As the valley is gouged wider and deeper the walls are cut and the sides of the mountain may fall on the glacier. Thus, enormous boulders as well as much loose material gather on the surface of the glacier and move with it.

As the glacier reaches lower altitudes, where the climate is warmer, it melts and deposits material to form a *terminal moraine*. The glacier may continue to melt in the same region for many centuries. The deposit may therefore become hundreds of feet thick. Glacial deposits formed in this way are common throughout much of the northern part of Canada. They can easily be recognized because the boulders, pebbles, and clay are all mixed together; they do not form layers as in sedimentary rocks.

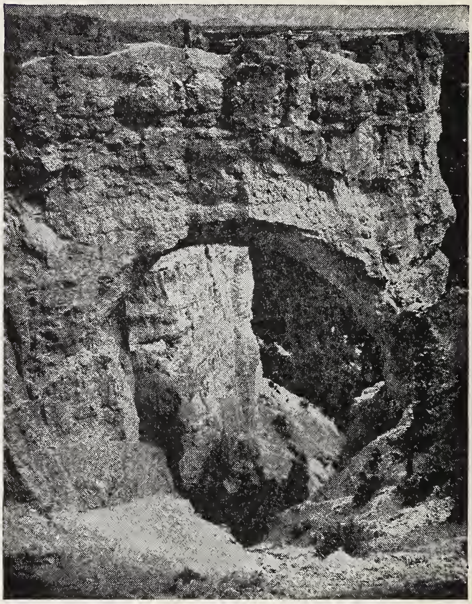
Glaciers are found mostly in the Himalayas, Andes, and Alps. In the United States they are rare; there are some in the higher peaks of the Cascade Mountains in Oregon and Washington. Farther north, however, in British Columbia and Alaska, there are a great many. The largest of these glaciers are in Alaska, some being 40 miles long and 1,000 feet thick. Many of them reach the sea, break up, and float away as *icebergs*.

The glaciers we have just described are called *valley glaciers*. Another type of glacier, known as a *continental glacier*, is an ice sheet that covers a wide area. Most of Greenland, for instance, is covered by an enormous continental glacier more than a mile thick.

There is much evidence to show that, in a relatively recent geological period, glaciers covered large areas of northern Europe and North America. During the Ice Age the whole of Canada was covered by ice that extended as far south as New York City. Indeed, Long Island is an enormous moraine. In the region of New York City one can find rocks polished and scratched by glacial action, and there are also numerous glacial deposits in the New England states.

Chemical Weathering. The wearing of rocks by impact or pressure is usually called *mechanical weathering*. Wearing due to the reaction of carbonic acid and rock material is called *chemical weathering*. Carbon dioxide dissolves in water to form carbonic acid. Although this is a weak acid that dissolves rocks very slowly, the total effect over a long period of time may be enormous. Such rocks as limestone or marble are especially subject to chemical weathering, whereas rocks like shale, quartz, and basalt are worn, for the most part, by mechanical weathering.

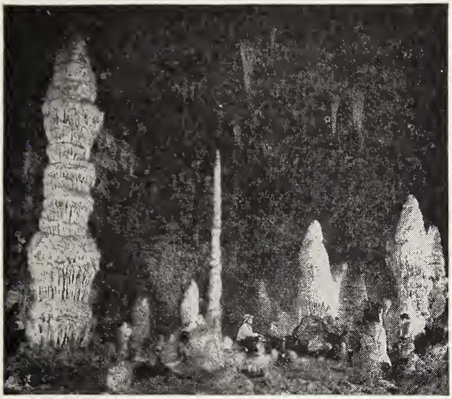
Limestone rocks are particularly affected by carbonic acid. As the water containing carbon dioxide trickles slowly along the joints of limestone rocks, the rock is dissolved; the joint becomes a crack, and the crack eventually becomes so large that it forms a cave or cavern. Carlsbad Caverns in New Mexico, Mammoth Cave in Kentucky, and other large caverns have been formed in this way, that is, by the dissolving power of running water.



Courtesy Union Pacific Railroad

Fig. 10–5. A natural bridge in the weathered rocks in Bryce Canyon National Park.

Stalactites and Stalagmites. Among the most impressive features of limestone caverns are the long "icicles" of stone, called *stalactites*, that are suspended from the ceiling, and the broader deposits, called *stalagmites*, that rise from the floor. As the surface water seeps through the limestone it dissolves some of the calcium carbonate. When the water reaches the ceiling of the cavern, it clings there, forming droplets. Then the water evaporates, the carbon dioxide escapes, and some of the calcium carbonate remains deposited on the ceiling. If this process is continued over a long period of time, the deposit grows into a stalactite. Some of the water that seeps through the rock falls to the floor of the cavern and evaporates there. In this way a stalagmite is started. A stalagmite grows upward; and, if the process continues long enough, a stalactite and a stalagmite may join to form a column.



Courtesy Santa Fe Railway

Fig. 10–6. Stalactites and stalagmites in the Carlsbad Caverns.

Action of the Sea. The sea is also a powerful eroding agent, particularly along the shore line. During storms the waves hurl sand, pebbles, and even large boulders against cliffs with great violence. As a result the cliffs are weakened and parts of them may collapse upon the beach. The rock fragments are then constantly rolled back and forth by the waves so that they are worn and rounded to form pebbles, and the pebbles may eventually be further ground to sand.

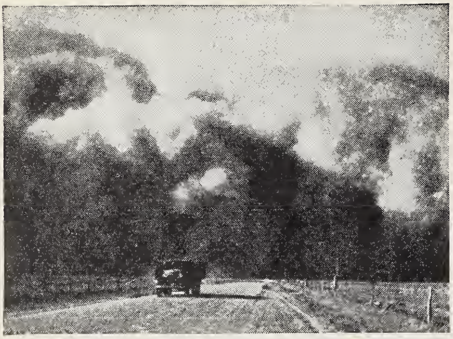
Destructive Effects of Erosion. Such natural features of the earth as the broad plains, the rounded hills, the rugged mountains, and even the sparkling waterfalls are nearly all caused by erosion. But we must remember that, while erosion is responsible for our magnificent scenery, it also slowly destroys the land mass. Indeed, it has completely erased whole mountain chains and washed away continental areas. The material taken from the land is carried to the sea, where it is again compressed into rock layers. In the course of time these deposits may be uplifted to make new lands; and these, in turn, will be attacked by the forces of erosion. Thus the cycle goes on indefinitely.

Soil and Its Conservation. ✓ If you travel across the country, you will notice that the natural plant growth changes from place to place. In one place there may be pine and fir; in another, maple; in another, oak; and in still another, rhododendron. Why do these differences exist? They are due largely to differences in the chemical composition of soils.

If the bedrock is almost horizontal, the small fragments remain on the surface and in time are weathered to particles that form soil. But soil is not merely disintegrated rock. Living microscopic organisms, called *bacteria*, bring about chemical changes in the soil that make it possible for plants to live. The soil is also enriched by the remains of vegetation that has lived and died there. Animals, such as earthworms, tunnel in the soil and thus permit air and water to reach the soil particles.

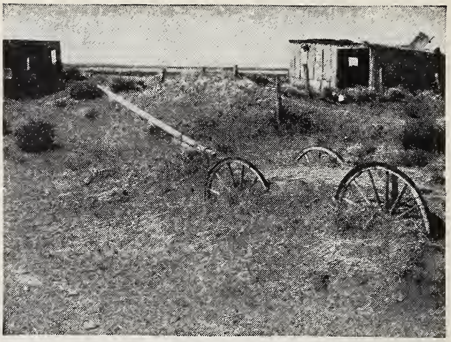
Limestone rocks, for example, contain insoluble impurities such as clay. After the rains have dissolved the lime, the clay remains to form soil. In the Appalachian valleys the soils above the limestones are rich, whereas those above the shales are poor.

The depth of soil varies considerably, depending on the slope of the ground and other factors. In the temperate zones of the



Courtesy U.S. Soil Conservation Service

Fig. 10–7A. An approaching dust storm.



Courtesy U.S. Soil Conservation Service

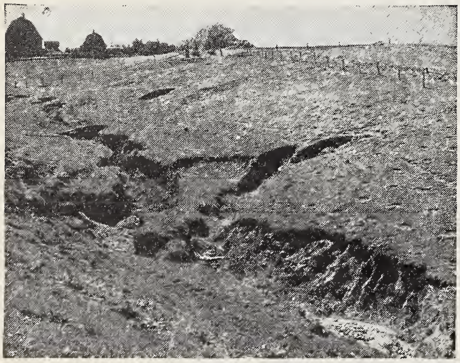
Fig. 10–7B. Destruction of farmland caused by a dust storm such as that pictured in Fig. 10–7A.

earth the soil usually ranges from two to five feet in thickness, although the rich topsoil is seldom more than a foot deep.

Soil is one of the natural resources of the earth. Without it plants would not grow, and without plants animals could not live.

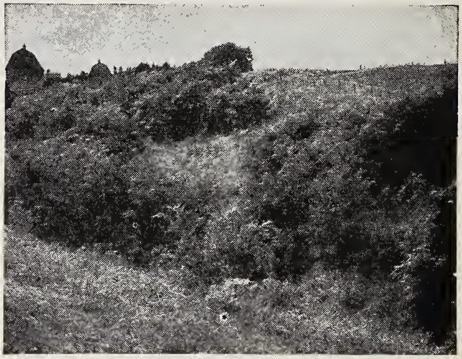
Soil Erosion. Where land is cultivated or laid bare by the destruction of forests, rain and wind can cause rapid erosion of the soil. Unless this is halted, it may result in losses that cannot be recovered. Before our Midwest was settled, the prairies were covered by native grasses. Once the grass was removed, the topsoil was exposed to high winds which, in these arid regions, have a highly destructive effect. Dust storms arise in the "Dust Bowl" of Kansas, Oklahoma, Texas, and Colorado. In 1934, after a long drought, violent dust storms caused great and widespread damage. It is estimated that more than 300,000,000 tons of topsoil were blown away to the east, and much of it was lost in the Atlantic Ocean.

The destruction of soil by erosion is due



Courtesy U.S. Soil Conservation Service

Fig. 10–8A. A badly eroded pasture showing the deep gully formed by the rapid runoff of surface water after a rainstorm.



Courtesy U.S. Soil Conservation Service

Fig. 10–8B. The same pasture illustrated in Fig. 10–8A several years after trees and shrubs were planted to control the runoff of surface water. Note that the erosion has been completely halted.

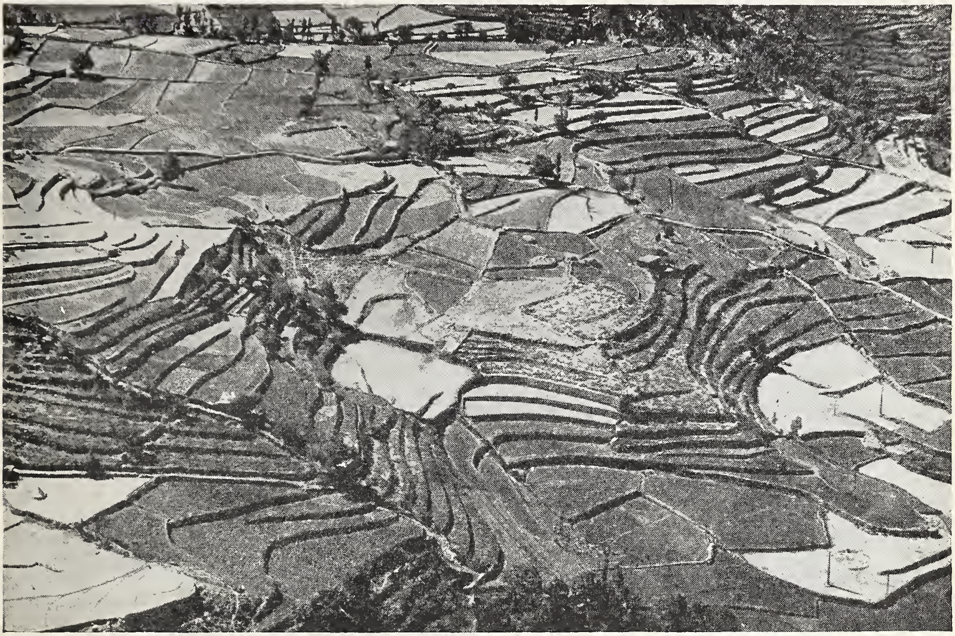
largely to poor farming and lumbering practices. The annual loss of plant nutrients washed out of the soil by erosion is six times the amount used by the plants. In the United States alone thousands of square miles of good farmland have been ruined by soil erosion.

Methods of Soil Conservation. Canada and the U.S. are now trying to halt soil erosion by conservation. The lands that suffer most are those with a marked slope. The steeper the slope the greater the speed of the surface waters after a rainstorm, and the greater the loss of soil. Gullies form easily on sloping land; a single thunderstorm may form gullies two feet deep. Unless checked, they grow at a rapid rate, carrying away much of the fertile land.

The problem of soil conservation is not simple. The aim is to check the speed of surface water in order to reduce erosion. Three methods are used—terracing, contour plowing, and strip cropping. The method used depends on local conditions.

Terracing prevents erosion by breaking up a long slope into a number of shorter and gentler ones. It is the oldest and most effective method of soil conservation. It was used by the Incas in Peru, and the Chinese have used it for centuries. In terracing, the slope is changed to a series of steps held in place by retaining walls. Retaining walls are expensive, however, and instead parallel earth ridges are often built across the slope.

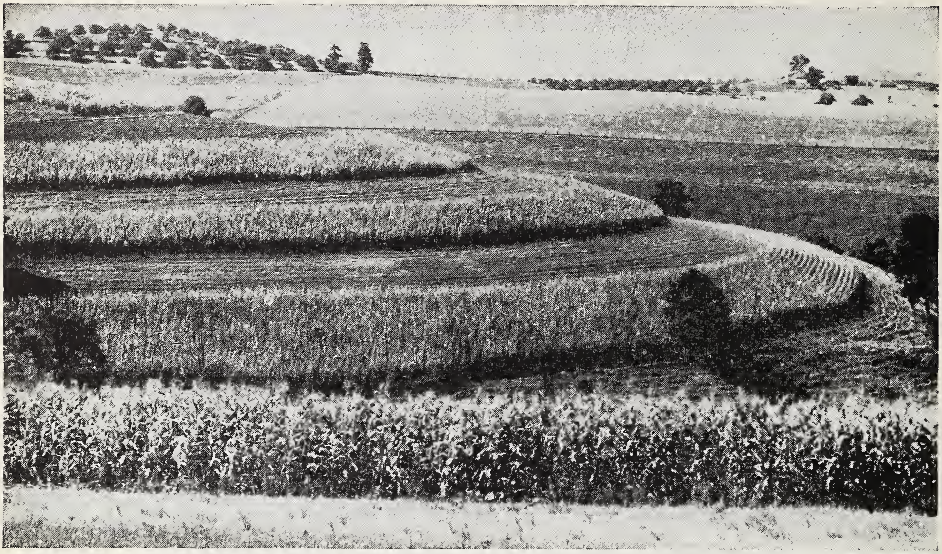
In 1813, Thomas Jefferson wrote to a friend concerning his farm in Virginia: "Our country is hilly and we have been in the habit of plowing straight rows, whether up or down hill. Our soil is rapidly running into the



Courtesy U.S. Soil Conservation Service

Fig. 10–9. This remarkable photograph shows the terracing of a steep valley in Lebanon, Syria.

rivers. We now plow on dead level, following the curvature of the hills. Every furrow acts as a reservoir to retain waters, all of which go into the growing plant instead of running off into streams." This is known as *contour plowing.* Furrows are made around the slope, not up and down; that is, they follow the contour of the hill. The furrows make a series of dams that hold the water, giving it time to soak into the soil.



Courtesy U.S. Soil Conservation Service

Fig. 10–10. Contour strip cropping on sloping land. Note the alternate belts of grain and clean tilled crops along the contour of the slope.

Sometimes rows of crops, such as corn, potatoes, and tobacco, are alternated with rows of grain crops. Grains have fibrous roots that grow close together and do not allow the water to run off. This alternation of types of plants is called *strip cropping.*

THINGS TO REMEMBER

Erosion is the wearing-away of rock surfaces and the removal of the loosened material.

Running water and glaciers are important *eroding agents.*

Mechanical weathering is the wearing-away of rocks by impact; *chemical weathering* is due to the solvent action of carbonic or other acids.

Caves and *caverns* are formed by chemical weathering.

Stalactites and *stalagmites* are "icicles" of stone formed in limestone caverns. Stalactites hang from the ceiling; stalagmites rise from the floor.

Soil results from the disintegration of rock and the subsequent activity of plant and animal life.

Topsoil is eroded where it is exposed on unprotected surfaces.

Terracing, contour plowing, and *strip cropping* are methods of *soil conservation.*

QUESTIONS

A

1. Determine which of the following statements are true and which are false. Then correctly reword the false ones.

- (*a*) Mountains are formed by the cooling of the earth's interior.
- (*b*) The expansion and contraction of rocks cause weathering.
- (*c*) Talus is a pile of debris at the base of a cliff.
- (*d*) A moraine is rock waste from the bottom of a glacier.
- (*e*) Glaciers, in past ages, have reached the latitude of New York City.
- (*f*) Soil is disintegrated rock.
- (*g*) Terracing is one method of conserving the soil.

2. Name three methods by which rock surfaces may be weathered.

3. Explain the terms: (*a*) delta; (*b*) moraine; (*c*) talus; (*d*) contour plowing.

B

4. Name four agents that cause erosion. Which is the most effective? Why?

5. What are the main differences in the erosion caused by the Colorado and Mississippi rivers?

6. "A river gradually widens and deepens its bed." Explain carefully what this statement means.

7. What is a glacier? How does it act as a transporting agent?

8. What is soil? How is it formed?

9. Explain the need for soil conservation and discuss one method that is practiced for this purpose.

10. What are stalactites and stalagmites? How are they formed?

11. What is the difference between chemical and mechanical weathering? Give an example of each.

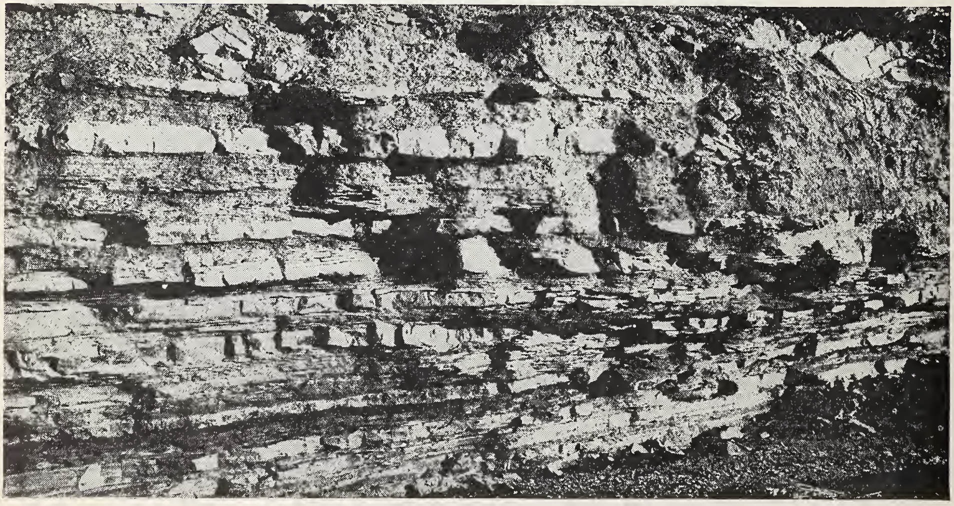
12. By a study of a map, note the significance of the glacier shown in Fig. 10–4 as a source of rivers. What streams does it feed?

Chapter 11

THE RECORD OF ROCKS

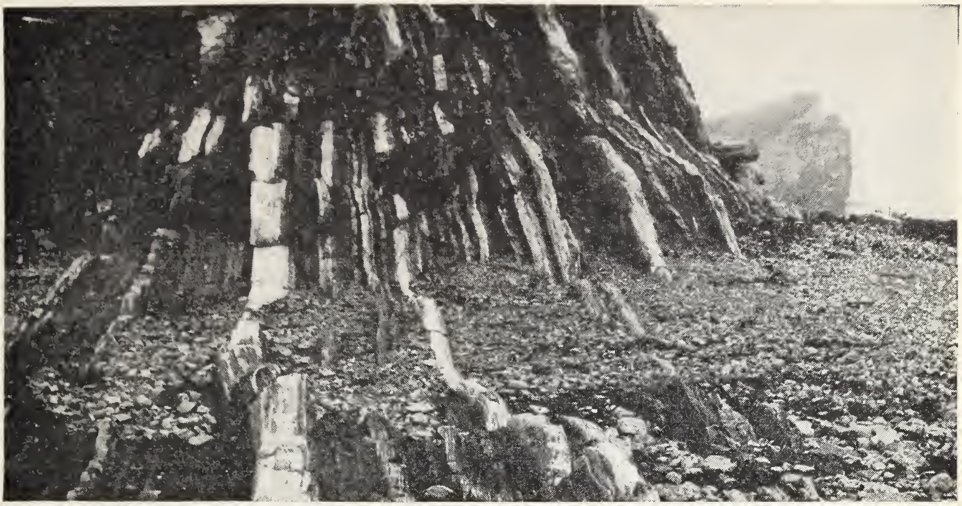
If you look at the rocks in the cut side of a hill or quarry, you may notice that they are arranged in layers, or *strata*. This is characteristic of sedimentary rocks, which were laid down in horizontal layers. When a river deposits its load of sediment, it does not dump all the material in the same place on the sea floor. We learned in Chapter 9 that there is a sorting of the deposits according to their size. As the speed of the running water is checked, the first load to be dropped is 1 *gravel*; as it is further slackened, 2 *sand* is dropped; and, finally, 3 *mud* & shale is deposited far out at sea.

Suppose, now, that for some reason, such as spring rains, the velocity of the river changes. As the speed is increased, the materials in the river are carried farther out to sea before being deposited. Each new deposit will therefore have a different texture from that of the old one beneath it. These deposits form in layers called *strata*, and sedimentary rocks are called *stratified* rocks. Differences between strata may also be caused by differences in the load carried by the stream. Strata may be only one-tenth of an inch thick or several feet thick.



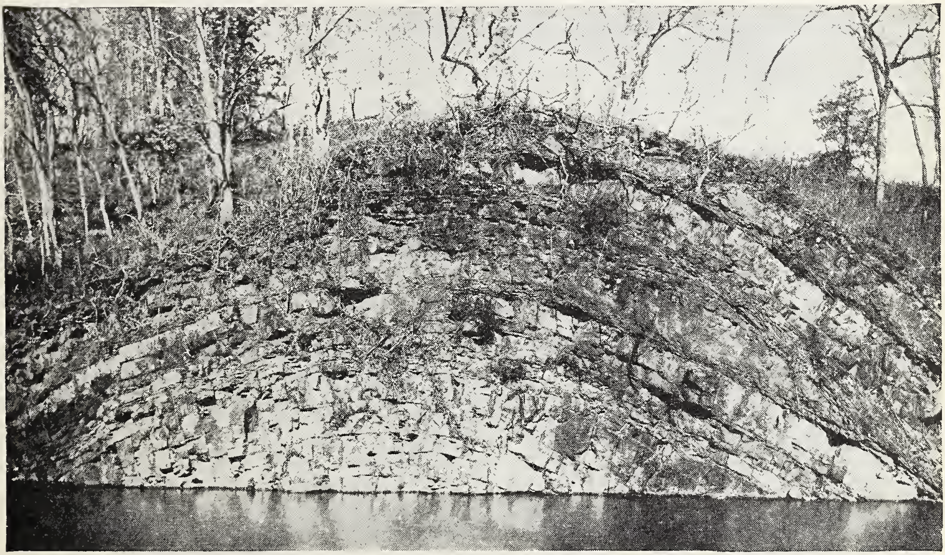
Courtesy U.S. Geological Survey

Fig. 11–1. Alternate beds of limestone and shale.



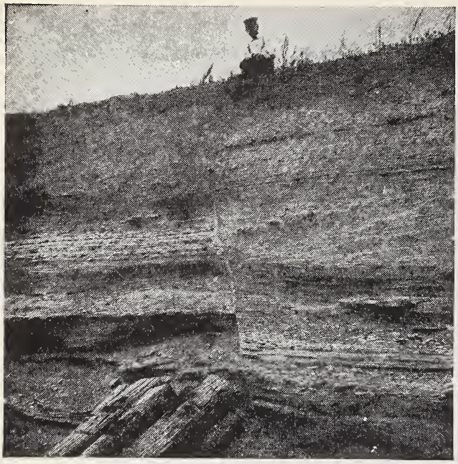
Courtesy Canadian National Railways

Fig. 11–2. These sedimentary rocks were laid down horizontally but they have been tilted by earth movement so that the beds are almost vertical.



Courtesy U.S. Geological Survey

Fig. 11–3. Folded sedimentary rock.



Courtesy U.S. Geological Survey

Fig. 11–4. A fault.

Folds and Faults. Although sedimentary rocks were laid down horizontally, they are often tilted and sometimes bent. The bending is caused by the tremendous pressure exerted upon the rocks during the movements of the earth's crust. The process of bending rocks is usually called *folding*. Folds are sometimes so large that a single bend may extend for several miles; or, on the other hand, they may be so small that several folds may be observed in the same cliff or quarry.

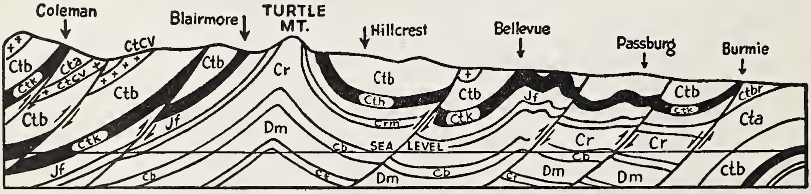
Sometimes pressure causes rock layers to break so that on one side of the break all the layers slide up or down. Thus each layer on one side of the break is on a different level from the same layer on the other side (see Fig. 11–4). This is known as a *fault*.

The Appalachians. The Appalachian Mountains are made of sedimentary rocks. Their strata have been sharply folded and faulted by pressure exerted from the southeast toward the northwest. This explains the northeast-southwest line of the range. The tops of the folds have been cut away by erosion, but the bottoms are deeply buried and protected from erosive forces.

Not all strata are equally resistant to erosion. Hard sandstone, softer shale, and slightly soluble limestone vary in their proportions in successive layers. After the folding took place, the upturned edges of all these rocks were eroded, but the softer shale was eroded much faster than the sandstone, and the limestone was dissolved away. As a result, the edges of the upturned sandstone now form the peaks and ridges of the Appalachians, and the shale and limestone are generally found in the valley bottoms.

Many questions might be asked concerning geological history, that is, the history of the earth. We can find the answers in the records of past ages as they are written in the rocks. Such a history is not nearly so definite as human history, but the stories have much in common.

Human History. If we wish to learn something of man's life on the earth, we read his-



Courtesy The Institute of Applied Arts, Ltd.

Fig. 11–5. Section in Crowsnest Pass to show the structural relations of the Kootenay Coal measures (black); horizontal distance represented is about 10 miles; *Cf* Flathead quartzite (Cambrian), *Dm* Minnewanka limestone, *Cb* Banff Shale, *Ctk* Kootenay coal measures, *Ctb* Blairmore sandstone, *Cta* Alberta shale, *Ctbr* Belly River sandstone; note the synclinal structure of the coal basins.

tory. The historian has many records to cover the immediate past, but the further back he goes the fewer are the records, until eventually there are no written records at all.

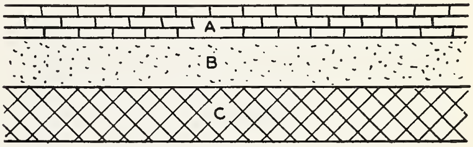
In the beginning man was a savage. He had no form of language, and his living was not much better than that of the beasts among which he lived. He had to obtain food and protect himself against wild animals with his bare hands. He ate his food raw because he had not learned to build a fire. After several hundred thousand years of this savage life, he learned to make a fire to frighten wild beasts. He also learned to make spears that gave him an advantage over animals. When he discovered that he could use the ragged edge of a broken stone for cutting things, he was able to shape stones into tools and weapons. Man had then entered what we now call the *Stone Age*.

Stone tools and weapons as well as the remains of early man and mammals are found in the same rock strata. These are the clues that give us information about the life of early man long before any written records were made; they are records in the rocks.

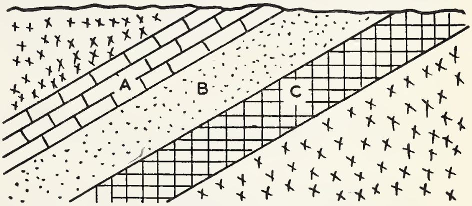
Although our written records of human life on the earth go back only about 5,000 years, the records in stone show that man has existed for about 1,000,000 years. Geologists believe that the earth is at least 2,000,000,000 years old. Compared with these figures, the length of recorded history is very small. A good way to compare these periods is by the following analogy: If we represent the age of the earth by the height of the Empire State Building in New York (1,250 ft.), then a dime placed on top of the tower will represent the length of recorded human history.

Earth History. Just as we find out about ancient man's life on the earth, so we can learn much about the history of the earth itself. How long have living things existed on the earth? Did animals exist before plants, or vice versa? What were the earliest animals like? These and many other questions come to mind when we think of the earth's history.

In order to answer these questions, the geologist reads the records in the rocks of the earth's crust. He looks for clues like a detective working on a criminal case. He compares the clues he finds in one region with those he finds in another. When he puts the evidence together, he has considerable information about the climate in different geologic periods and about life as it developed on the earth ages ago.



Horizontal Rock Strata



Tilted Rock Strata

Fig. 11–6. *A* is a more recent bed than *B*, and *B* is more recent than *C*.

A great deal of geological history can be obtained from the *position* of rock strata. As we look at a series of exposed sedimentary rocks consisting of beds of shale, sandstone, and limestone we see the following picture: Shales were once muds that were carried by rivers and laid down in a fairly shallow sea; sandstones were once the loose sand of beaches or deposits laid down near the shore; limestones are composed mostly of the broken remains of animals or of calcium carbonate precipitated from solution in shallow waters.

But this is not the only information we can

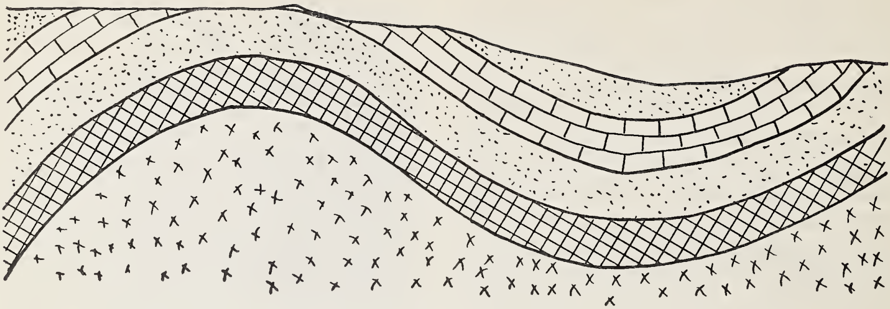


Fig. 11–7. The rock strata have been folded and the surface rocks eroded.

obtain by examining a series of bedded rocks. Geologists have learned that *the younger beds of rock rest upon the older beds*. This is true of all the sedimentary rocks in the world, and it has enabled geologists to compare rocks in widely different regions. The illustration of the horizontal rock strata in Fig. 11–6 shows that the uppermost layer, *A*, is the most recent; the second layer, *B*, was deposited earlier than the top layer, *A*, but later than the third layer, *C*.

Now let us turn to the other part of that same figure, which shows rock strata that have been tilted. Again it is clear that, since the older beds lie underneath the younger ones, the oldest beds are on the right of the diagram, whereas the youngest are on the left. In other words, we can go through rock layers just as we can turn backwards through the pages of a diary—from recent records to older and still older records.

An Unconformity. In some areas strata of great thickness, even thousands of feet, show that the sediments were deposited under the same conditions for a long period of time. Such strata may be tilted and folded. Suppose

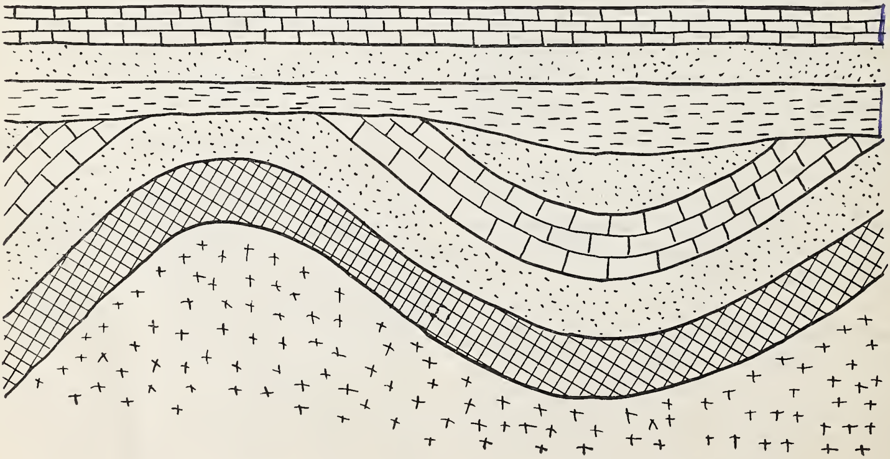


Fig. 11–8. Recent horizontal beds rest unconformably upon the older beds.

that in a later period the rocks are raised by earth movement above sea level so that they form dry land. The exposed rock surfaces are then weathered and worn by running water and other agents of destruction. In the course of time the worn strata may look like those shown in Fig. 11–7. If, at a still later period, the rocks are again lowered below sea level, a fresh series of strata will be laid down as horizontal beds on top of them, as shown in Fig. 11–8. The line of separation between the newer and the older beds is called an *unconformity*.

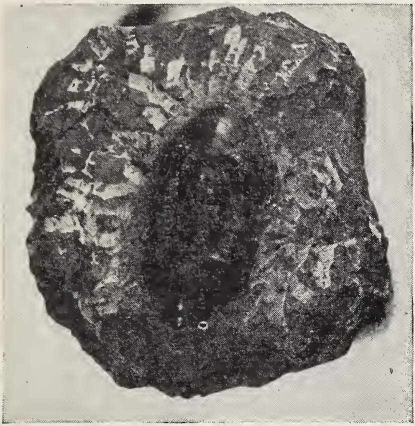


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Fig. 11–9. Fossil trilobite embedded in rock.

Unconformities are common. They are important clues to geological history because an unconformity indicates a lapse of time between the folding of the lower, or older, rocks and the depositing of the upper, or younger, rocks. Thus they help geologists to determine the sequence of events in geological history by showing the *relative* ages of various rocks. If, however, a geologist wishes to know how long the period of submergence or erosion was, he needs further evidence. This evidence he finds in fossils.

Fossils. If you examine a sedimentary rock, you may find seashells embedded in it. These shells are the remains of animals that lived ages ago. They are called *fossils.* The term *fossil* has several meanings. Some fossils are the bones or shells of animals; others are the impressions of shells left in rocks after the shells have been dissolved; and others, again, are the imprints of leaves or the footprints of animals.

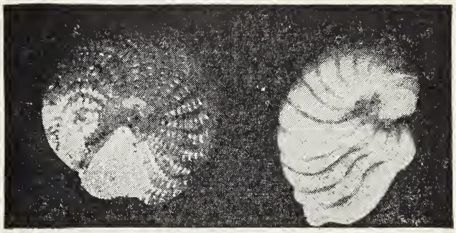

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Fig. 11–10. Fossils showing curved segments.

Relatively few animals become fossilized, since most of them are either devoured by other animals or die and decay in the open air. An animal, or part of it, can be preserved only if it is protected against the chemical effects of air by quick burial in something like sand or mud or ice. For this reason fossils of land animals are relatively scarce. In the sea, however, conditions for the preservation of some part of an animal are more favorable. When a sea animal dies, it sinks to the sea floor. The soft parts decompose, but the hard shell may be covered by sediment before the sea water has seriously affected it. The shell then becomes a fossil in the sedimentary rock.

THINGS TO REMEMBER

Sedimentary rocks are usually made up of strata, which may be bent or folded.

Sediments deposited in water are usually sorted according to the size of the particles.

A *fault* is formed when rock layers break and slide up or down along a break.

The *age of sedimentary strata* can be found from their position and from the fossils they contain.

Younger beds of sedimentary rock rest upon *older* beds.

An *unconformity* is an irregular line of separation between newer and older beds.

Fossils are bones or shells or impressions of animals or plants that lived in past ages.

QUESTIONS

A

1. Explain, giving diagrams: (*a*) folding; (*b*) faulting.

2. Fossils are not found in igneous rocks. Why not?

3. Suppose a layer of limestone rests upon a layer of shale. Which is probably the older? Why?

B

4. Explain the causes of the structure of the Appalachian Mountains.

5. What is an unconformity? What information does it give to historical geologists?

6. What do the following tell us about the history of the earth: (*a*) order of rock layers; (*b*) fossils?

PROJECT

Searching for Folds and Faults. If there are any cliffs or quarries in your neighborhood, examine them to see if the rocks are folded or faulted. Trace the strata across the fold. If there is a fault, look carefully for matching strata. If the rocks are sedimentary, look for igneous intrusions. If they are glacial, notice the absence of sorting.

Chapter 12

LIFE IN EARTH HISTORY

Many times through the ages great floods, which lasted for millions of years, have covered large portions of the earth. Some parts of the earth were submerged, or covered with water, and others were not. The whole of Europe, for instance, was flooded several times while large areas of North America remained dry.

During the periods of submergence, deposits were laid down and fossils collected in the beds. Flooding was followed by an elevation of the land, and the forces of erosion then came into action. When the land was again submerged, the new deposits formed an unconformity with the old ones. The fossils in these new deposits usually show that the animals changed greatly in structure, and some even became extinct.

Geological time is divided into five great eras:

Archeozoic — earliest life
Proterozoic — primitive life
Paleozoic — ancient life
Mesozoic — middle life
Cenozoic — recent life

Each of these eras is named according to the type of life that existed at the time. The comparative duration of these eras is shown in Fig. 12–1. Man's existence, in geological time, dates from the latter part of the Cenozoic era. This era is of comparatively recent origin—it began about fifty million years ago.

Archeozoic and Proterozoic Eras. Archeozoic and Proterozoic rocks consist of granites and sedimentary layers that may be as much as 100,000 feet thick. They were deposited during hundreds of millions of years. These rocks have been folded, faulted, and metamorphosed, and show little evidence of life. The record is therefore incomplete. They once formed the cores of mountains, but ero-

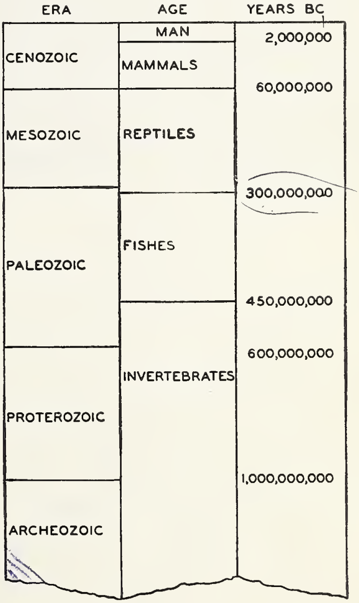


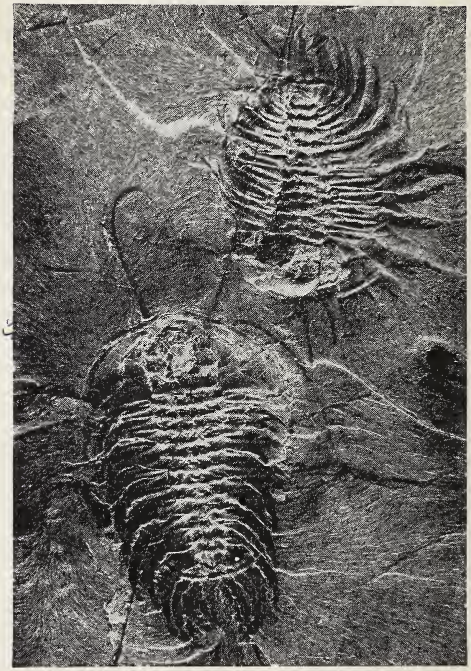
Fig. 12–1. Divisions of geologic time.

sion has uncovered them so that in many parts of the earth they are now exposed on the surface. The largest outcrop of these ancient rocks is in eastern Canada, where almost 2,000,000 square miles of them are exposed.

The Paleozoic Era. In the history of the earth, as recorded in the rocks of the Archeozoic and Proterozoic eras, some pages have been torn and other pages are missing. In the Paleozoic era, however, the record is fuller, and the chronological sequence of events is therefore more apparent.

At the beginning of the Paleozoic era, the North American continent was uplifted beyond its present boundaries so that land extended for hundreds of miles into the areas now known as the Atlantic and Pacific oceans. At a later period, water completely covered the North American continent for millions of years. In these early Paleozoic seas were deposited sediments that are the basis of much of our industrial wealth today. For instance, the slates of Pennsylvania, New York, and Vermont resulted from shales laid down at that time. Vermont marble is metamorphosed Paleozoic limestone. The extensive salt deposits in New York and Michigan were left by the Paleozoic seas. Much of the oil and natural gas, particularly in the Oklahoma region, is found in the Paleozoic sedimentaries. It is the animal life of this early period, however, that we find most interesting.

Life in the Early Paleozoic Era. For millions of years during the early Paleozoic era, the only living animals were *invertebrates*—animals without backbones. The seas held invertebrates of many kinds. At first these animals found food and shelter among the seaweeds that were also plentiful at this time. As the animals increased in numbers, there was more and more competition among them for the limited supply of food. As a result they probably began to attack and eat one another. In the course of time they developed hard shells with the calcium carbonate they extracted from sea water. Later some of them became fossilized. These fossils are the first definite records in sedimentary rocks. All these early animals lived in the sea, not on the land. It was millions of years before animals learned to breathe air. Until they could do this, there was no life of any kind on the land. The land was even bare of vegetation. It must have looked as desolate as the moon looks today.



Smithsonian Institution

Fig. 12–2. Trilobites. Note the antennae and the legs.

A common fossil of this period is that of a lobster-like animal called a *trilobite*. The trilobite was divided into three lobes, or divisions, by two furrows extending the length of its body. Trilobites lived in the Paleozoic seas. In their search for food they either crawled over the sea floor or swam just above it. Most trilobites were less than four inches long, but some types grew to more than a foot in length. Although there were many kinds of animals at this time, the trilobites were more numerous than all the others taken together; they were the ruling class of the early Paleozoic era. They existed for millions of years and then, for some unknown reason, they became extinct at the close of the Paleozoic era. Some kind of trilobite must have survived, however, because our shrimps, lobsters, and crabs are their descendants.

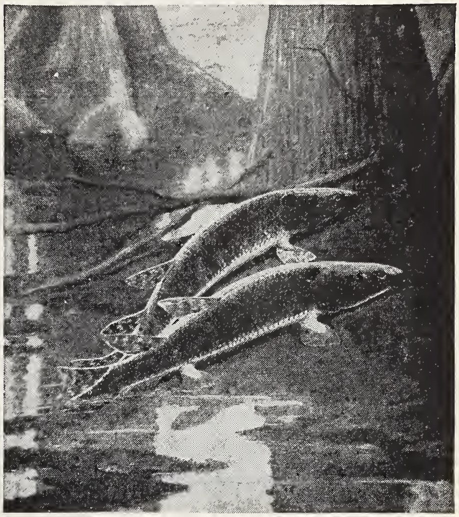
Late Paleozoic Era. In the middle of the Paleozoic era many mountains were raised in Europe. The central North American sea, however, remained almost unchanged. At this time the famous limestones were laid down in the Mississippi Valley. Some of these, particularly the Indiana limestones, are among the best building stones in the world.

Toward the close of the era the seas withdrew from central North America. This area became swampy land; vegetation thrived and became the origin of our extensive coal deposits. These deposits are important to our civilization because our industrial power has resulted to a large extent from the use of coal.

The Appalachian coal field, as it is called, is the largest in the world, but other coal fields were also formed. The coal in the British Isles, in the Ruhr and Saar basins in Germany, in the Donetz Basin in Russia, and in parts of Belgium and Poland were all formed at this time. At the same time the rich oil deposits of Pennsylvania, Kansas, Oklahoma, Illinois, and Texas were being formed. You will learn more about the formation of coal and oil in later chapters.

Life in the Late Paleozoic Era. The vegetation of the Paleozoic era had little resemblance to the vegetation we see today. It consisted of tall, dense forests of club mosses, horsetails, and ferns that grew into giant trees, sometimes reaching a height of 100 feet with trunk diameters of four feet or so. In the middle Paleozoic, fishes appeared for the first time. They were the first animals with backbones, usually called *vertebrates*, on the earth. From these few strange Paleozoic fishes have developed the great variety of fishes in the seas today.

During the latter part of the Paleozoic came the *amphibians* ("double life"). They are descendants of fish. Amphibians lay their eggs in water. The embryo hatches, like a tadpole, equipped with gills so that it can live in water. Later a lung replaces the gills, and limbs appear. The creature can then leave the water and live on land. Although amphibians were the first animals to live on land—the first to breathe ordinary air—they always returned to the water to lay their eggs.



American Museum of Natural History

Fig. 12–3. Early amphibians. This picture shows a stage in the development of lungfish into amphibians as reconstructed by W. K. Gregory. Lungfish learned to leave the stagnant pools and to move aimlessly about the banks in search of food.

The amphibians grew in size and flourished greatly. They almost became extinct, however, in Mesozoic times. The only remaining

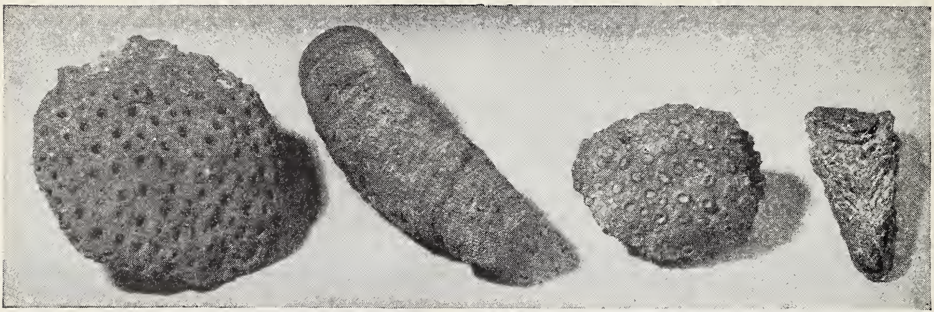


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Fig. 12–4. Corals.

amphibians today are a few small animals such as frogs, toads, and salamanders. Some descendants of the amphibians managed to overcome their dependence on water; they migrated to dry land and stayed there. These amphibians became the *reptiles* that conquered the earth and remained in unchallenged possession for about a million years.

The Mesozoic Era. Toward the end of the Paleozoic era a magnificent mountain range was raised along the present site of the Appalachians. During the Mesozoic era these mountain peaks were almost completely worn away by rain. At the end of this era there was again much mountain building, and the present Appalachians were raised. Between

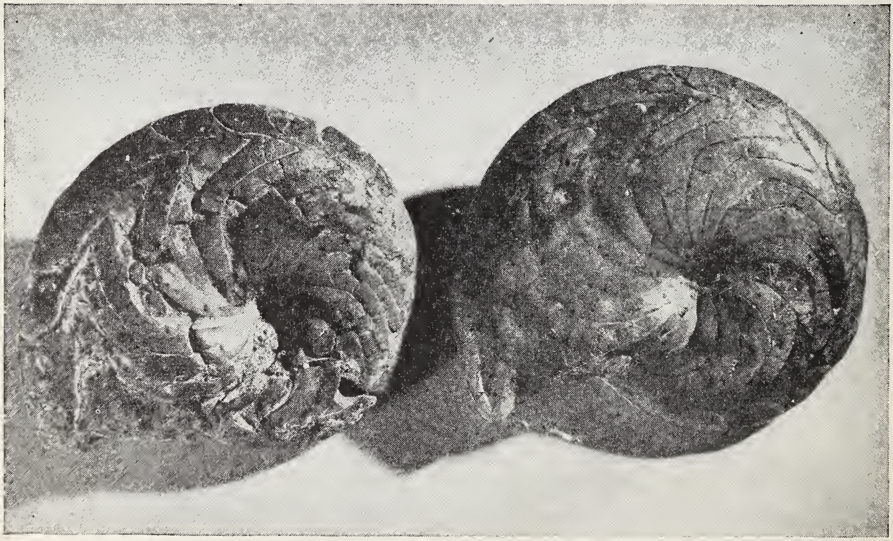

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Fig. 12–5. Ammonites are coiled like a watch spring.

Brent Jone

these two periods of uplift there was a long period of submergence, during which the white cliffs of Dover were formed, as well as the chalk in Colorado and the sandstones of the Dakotas and Montana. Mesozoic deposits in Wyoming and Montana are rich in vertebrate fossils; indeed, they are one of the most famous hunting grounds in the world, particularly for dinosaurs.

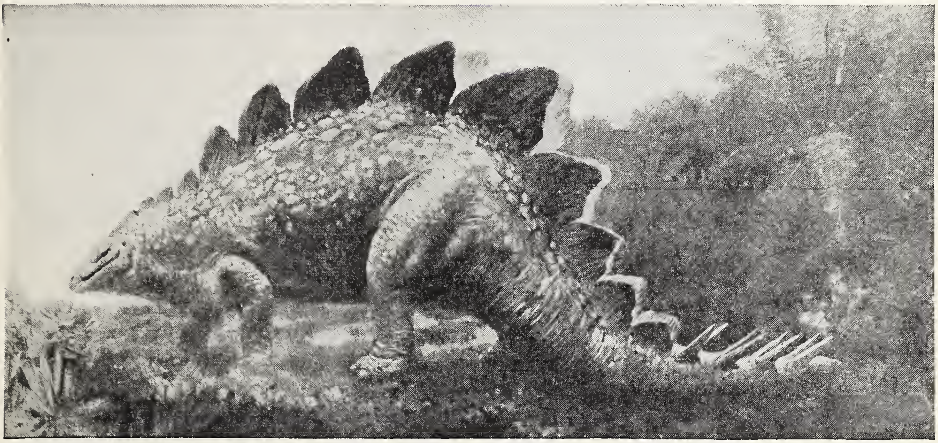
Life in the Mesozoic Era. During the Mesozoic era many new types of invertebrates and vertebrates appeared. Reef-building *corals* were abundant. Corals had lived in Paleozoic times but, unlike the trilobites, they did not become extinct but continued to thrive through the ages. Indeed, coral reefs are still being formed, particularly in many Pacific islands.

The most numerous shellfish in the Mesozoic era were the *ammonites*. They are easily recognized because their shells are usually coiled like a watch spring. The ammonites died out at the end of the Mesozoic era. An ammonite fossil proves, therefore, that the rock in which it appears was formed in Mesozoic or late Paleozoic times.

The Mesozoic era is characterized by the development of life on dry land. In particular, the small reptiles of the late Paleozoic developed into giant monsters called dinosaurs ("terrible reptile"). Some dinosaurs measured 100 feet in length and weighed as much as 50 tons. This was the *Age of Reptiles.* The giant reptiles were probably the most ferocious and powerful animals of all time. Yet, for some unexplained reason, they came to an abrupt end at the close of the Mesozoic. Today the only survivors of these mighty reptiles are lizards and snakes. The extinction of the reptiles is the subject of the following limerick:

There once was a plesiosaurus,
Which lived when the earth was quite
  porous;
When it first heard its name
It was covered with shame,
And departed long ages before us.

Some of the reptiles took to the air during the Mesozoic and became the forerunners of the birds. The most ancient birds had feathers like those of birds today, but they had sharp teeth and long tails like lizards. The ability to fly represents another advance in the life



American Museum of Natural History

Fig. 12–6. This member of the dinosaur group (*stegosaurus*) was armed with a double row of plates and spines down his back. (*Restoration by Charles R. Knight.*)

process as we see it unfolding: first, from sea to land animals, then from land animals to animals that fly.

The Cenozoic Era. The Cenozoic era began only about fifty million years ago and is the era in which we are now living. In spite of its youth, however, a number of significant geological events have already taken place. Most of the mountain ranges now in existence—the Rockies and the Himalayas, for example—were raised by the earth movements that occurred either at the end of the Mesozoic or in the early part of the Cenozoic.

The Rockies are the result of two different kinds of earth movement. First there was a great deal of folding and faulting at the end of the Mesozoic. Older strata were thrust eastward over younger sediments; thus Proterozoic and Paleozoic rocks rest upon Mesozoic, as illustrated in Fig. 12–7. In some areas the *overthrust* extends for a distance of from 20 to 30 miles. Then, in the early Cenozoic era, the Rockies were further uplifted, this time without much folding. Indeed, the extensive mountain chain running almost from pole to pole (the Rockies in the north and the Andes in the south) was raised at this time. The subsequent erosion of the Rockies during the past fifty million years has exposed the granite rocks that formed the core of the original mountain system. Mountain building during the Cenozoic was accompanied by a great deal of volcanic activity, and much of Washington, Oregon, and Idaho were covered with layers of lava thousands of feet thick.

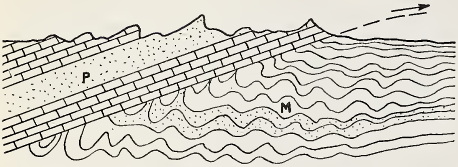


Fig. 12–7. In the overthrust in the Rockies of Montana, Proterozoic and Paleozoic rocks on the left have been pushed over younger Mesozoic rocks on the right.

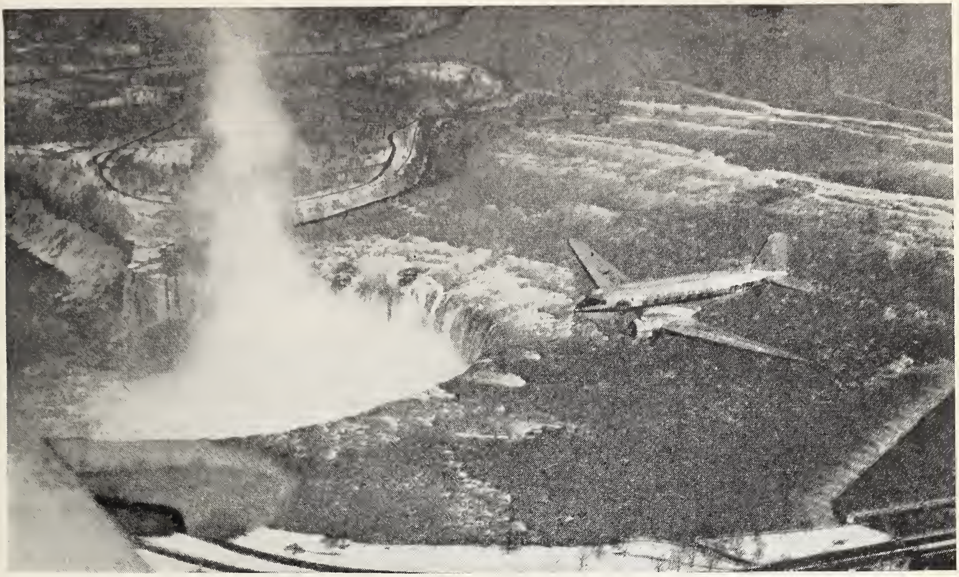
Most of North America has been above sea level throughout the Cenozoic era. The sea remained over the Gulf States for some millions of years, however, during which time sands, clays, and limestones were deposited in Texas and Louisiana. These formations are now of great economic importance, for they contain enormous deposits of natural gas, oil, and sulfur. About one-half of the oil drilled in the United States is obtained from these Cenozoic deposits.

Probably the most interesting sediments of this era are those deposited by ice in recent geological times. Geologists have proved that ice sheets descending from the Canadian highlands covered about half the United States at four different times. Glaciers scratched and eroded the valleys of the Rockies during this Glacial period. The Great Lakes and Niagara Falls can be traced to the effects of glaciers that retreated from the eastern United States and Canada only about twenty thousand years ago. There is reason to think that we are still in the closing stages of the ice ages.

Life in the Cenozoic Era. The Cenozoic era is usually referred to as the *Age of Mammals.* Mammals (animals that give milk to their young) date back to the Mesozoic. But in the Mesozoic they were rarely larger than a mouse or a cat, and they were no match for the giant reptiles. When the reptiles became extinct at the end of the Mesozoic, the mammals developed rapidly in size and kind. Soon they became the rulers of the land, a distinction they still hold.

There is evidence that many species living today existed fifty million years ago. At that time, the horse was no larger than a small dog, the rhinoceros was about two feet high, and the elephant stood about three feet tall. The mammals developed into two large groups, vegetarians and flesh-eaters.

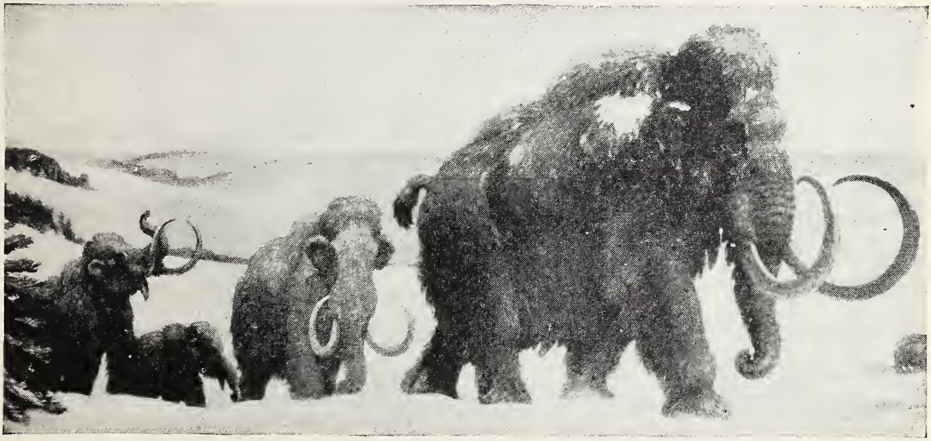
While some species of mammals have expanded, others have become extinct. For



Courtesy Trans-Canada Air Lines

Fig. 12–8. Niagara Falls were formed after the last Ice Age.

instance, twenty-five thousand years ago long-tusked mammoths with thick, hairy coats for protection against the intense cold were common. Now they have completely died out, and the only reminders of these ancient herds are the carcasses that are occasionally found completely preserved—hair, bones, and flesh—in the icy wastes of Siberia.



Chicago Natural History Museum

Fig. 12–9. The woolly mammoth was a common inhabitant of Eurasia and North America about 25,000 years ago.

One of the most interesting animals to trace in the Cenozoic rocks of North America is the horse. The oldest member of the horse family was a small animal, not more than a foot tall, with four toes on its front feet. Fossils in later beds in the Cenozoic show that the animal had grown to the size of a sheep and that the number of its toes had been reduced to three. Still later fossils show that the horse had grown to the size of a pony and that the middle toe had become so much heavier than the side toes that it supported all of the animal's weight. At a still later date, the modern horse appeared. This animal was still larger, and its middle toe had developed into the hoof; the side toes had become useless and had disappeared, except for little splints under the skin.

The record from the little four-toed creature to the modern horse is so complete that there can be no doubt about the development of the horse over fifty million years. No other mammal shows its growth or evolution so completely. An amazing number of fossils of horses have been found in the western part of the United States. Although wild horses roamed in great herds over the plains of North America, they, like the long-tusked mammoths, became extinct at the end of the ice ages. All the horses in America today are descendants of horses brought from Europe.

Development of Life on Earth. Life on the earth has developed from simple creatures to more complex types. After the invertebrates came the vertebrates; first fishes, then amphibians, then reptiles, then birds, then mammals, and, finally, man. As time went on, the living creatures adapted themselves to different conditions. Even such lowly animals as the trilobite, coral, and ammonite underwent marked changes in structure, as they are traced by their fossils through more recent rocks. These changes usually came about because they helped the animal to travel more rapidly or to obtain food more easily as enemies became more numerous and food harder to get. This response to changing conditions is what the geologist means by evolution.

Man is the latest development of life on the earth. In the beginning, man used his hands and even his teeth as weapons. Later he made weapons of stone, which he used to subdue all other creatures. As time went on, man stopped making tools merely for the purpose of protecting himself against animals; he used them to increase his comforts and to make his life easier and pleasanter.

After the Stone Age man learned to use metals. The first metallic substance he made, probably by accident, was bronze. It is supposed that early man placed lumps of copper and tin ores around his campfire and that the heat from the fire melted the metals together and formed bronze. Once he had learned to make weapons and tools out of bronze, man entered the Bronze Age, which began about five thousand years ago. Since it is much more difficult to smelt iron than copper, the Age of Iron came later.

Man still needs fire and metals to advance his civilization. Coal, petroleum, and steel are basic needs in our modern world. These will be discussed in later chapters.

THINGS TO REMEMBER

The *Cenozoic* is the era of recent life.

The *Mesozoic* is the era of middle life.

The *Paleozoic* is the era of ancient life.

The *Proterozoic* is the era of primitive life.

The *Archeozoic* is the era of earliest life.

Mountain building, followed by erosion and submergence, took place in all the eras.

The first *fossils* appeared in the early Paleozoic.

Invertebrates are found in early Paleozoic rocks.

Fishes, the earliest *vertebrates*, are found in late Paleozoic rocks.

Coal had its origins in the late Paleozoic.

The Mesozoic was the *Age of Reptiles*.

The Cenozoic is the *Age of Mammals*.

North America has had four *ice ages* during the Cenozoic.

QUESTIONS

(animals without backbones
with

A

1. Explain the following terms and give an example of each: (*a*) invertebrate; (*b*) vertebrate; (*c*) amphibian.
2. What could you conclude concerning the age of rocks in which were found: (*a*) trilobites; (*b*) ammonites?
3. Why are the late Paleozoic deposits important to the industrial life of the nation?
4. State whether the following are alive or extinct: (*a*) trilobite; (*b*) mammal; (*c*) coral; (*d*) dinosaur; (*e*) ammonite; (*f*) mammoth.
5. What are the differences between amphibians and reptiles?

B

6. (*a*) When were the Rockies formed? (*b*) In some parts of the Rockies older beds rest upon younger ones. How did this happen?
7. Write briefly on plant and animal life in the late Paleozoic era.
8. Describe life during the Mesozoic era.
9. What are some of the geological events of the Cenozoic age.
10. State briefly what you know of the development of life as revealed by rocks.

PROJECT

Collecting Specimens of Fossils. Write to the nearest college or university geology department and inquire whether there are any rocks in your region that are likely to yield fossils. Ask also for information concerning the age of such rocks and the kind of fossils to look for. Then, if possible, visit a museum where such fossils are on display. When you are familiar with the local fossils, begin the search.

REVIEW QUESTIONS ON UNIT 2

A

1. What is the meaning of the following words: (*a*) equinox; (*b*) latitude; (*c*) meridian; (*d*) igneous; (*e*) metamorphic; (*f*) strata; (*g*) Paleozoic?
2. State the meanings of the following terms or phrases: (*a*) parallels of latitude; (*b*) meridians of longitude; (*c*) basalt; (*d*) continental glacier; (*e*) fault.
3. Determine which of the following statements are true and which are false. Then correctly reword the false ones.
   - (*a*) The world is divided into 24 time zones, each of which differs from its neighbors by one hour.
   - (*b*) The width of a time zone is 15 degrees of longitude.
   - (*c*) The earth has an iron core.
   - (*d*) Shale and slate are sedimentary rocks.
   - (*e*) A continental glacier at one time covered the whole of North America.
   - (*f*) The Appalachians are older than the Rockies.
   - (*g*) There is no definite record of life on earth before the Paleozoic era.
4. How did Globigerina become chalk?
5. What are fossils?
6. State the meaning of the terms: (*a*) Paleozoic; (*b*) Cenozoic; (*c*) terracing; (*d*) invertebrate.

B

7. Explain by means of a diagram the cause of night and day.
8. Explain how and why the time in Chicago differs from that in New York and the time in Winnipeg from that in Vancouver.
9. What is a volcano? How is it formed?
10. How may an igneous rock become a sedimentary rock? How may a sedimentary rock become a metamorphic rock?
11. (*a*) Sketch a trilobite.
    - (*b*) Where would you expect to find trilobites?
    - (*c*) What do they indicate to the geologist?

12. Contrast the Mississippi River and the Colorado River as eroding agents.

13. What evidence is there that glaciers once covered part of Canada?

14. Contrast the Appalachians and the Rockies.

15. "Younger beds rest upon older beds." Explain. Why is this statement important to the geologist?

16. (*a*) Draw a diagram of an unconformity.
(*b*) What does an unconformity indicate to a geologist?

17. Describe some of the evolutionary trends in animal life during the Mesozoic era.

18. (*a*) What is the difference between folding and faulting?
(*b*) Draw a diagram of each.

19. (*a*) Why are marine animals more often found as fossils than land animals?
(*b*) Why would you be surprised to find a fossil in marble?
(*c*) What purpose do fossils serve in determining geological history?

SUGGESTIONS FOR FURTHER READING

A

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Unit 3

TEMPERATURE AND HEAT

13. WHAT IS TEMPERATURE?
14. WHAT IS HEAT?
15. EXPANSION
16. HOW HEAT TRAVELS
17. EVAPORATION AND BOILING

Chapter 13

WHAT IS TEMPERATURE?

A thermometer, as you know, is an instrument used to measure temperature. One of the first things a doctor does in making a physical examination is to take your temperature. He hopes to find your temperature normal, in which case his thermometer will read about 98.6° Fahrenheit. But if you have a fever, your temperature may be as high as 103° or 104°. On the whole, however, body temperature remains very nearly constant throughout our lives.

Of all the animals only birds and mammals maintain a constant temperature. Such animals are said to be *warm-blooded*. The temperature of *cold-blooded* animals, such as insects and fish, varies with the temperature of the air or water that surrounds them. In other words, they behave in this respect like a stone or other inanimate objects.

Insects, frogs, and snakes are cold-blooded. In winter they become so cold that they cannot live a normal life, and they either die or hibernate. It is for this reason that insects are not seen outside during cold winters; and birds that feed on insects must migrate to a warmer climate if they are to survive.

You might wonder why the doctor uses a thermometer to discover whether the patient has a fever. Why can't he determine this by simply touching the patient? The answer is found in the following experiment.

Demonstration 13–1. The Reliability of Touch in Measuring Temperature.

Fill three glasses with water—one with hot, one with cold, and one with lukewarm water. For about a minute hold a finger of your left hand in the hot water and a finger of your right hand in the cold water. Then transfer the finger from the hot water to the lukewarm water. Now remove this finger from the lukewarm water and place the finger from the cold water in it. One finger tells you the lukewarm water is cold, while the other tells you it is hot.

We have just seen how unreliable our sense of touch can be. In the exact work of science we must have some means of measuring temperature accurately. In order to see how this has been accomplished, think of temperature in terms of the motion of molecules. You learned in Chapter 4 that the hotter a substance is, the faster its molecules move. Hence we can say that temperature is an indirect way of indicating the speed of molecules. An increase in the speed of the molecules of most substances causes those substances to expand. Thus by measuring the expansion we have an accurate means of measuring temperature.

The Earliest Thermometer. The first thermometer on record was made by Galileo before 1600. It indicated temperature because air expands when heated. It consisted of a glass tube about 10 inches long with a glass bulb about 1 inch in diameter at one end. When the open end of the tube was put under water and the bulb warmed, bubbles of air escaped into the water, thus showing that the air inside the bulb had expanded. When the bulb was allowed to cool, the water rose part way up the tube to replace the air that had escaped. Any further changes in the temperature of the air in the bulb caused a change in the water level in the tube.

Demonstration 13–2. A Model of the First Thermometer. Blow a bulb about an inch in diameter on the end of a one-foot length of $\frac{1}{4}$-inch glass tubing. While the bulb is still hot place the open end of the tube under water in a beaker. Water rises in the tube as the bulb cools. Coloring the water with a little ink will make it easier to see the height of the water in the tube. The level of the liquid in the tube can be changed by heating the bulb for an instant or two in the Bunsen flame and then allowing it to cool.

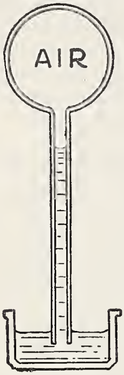
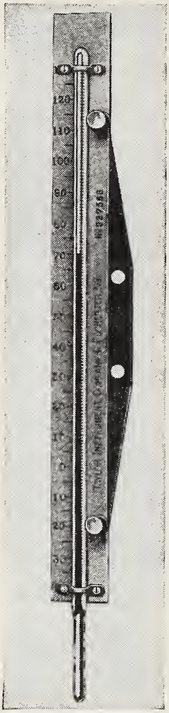


Fig. 13–1. An early thermometer of the type Galileo invented. It was not reliable because the height of the water also depended on the atmospheric pressure.

This type of thermometer was used by doctors in the 17th century. To find a patient's temperature, the doctor first placed the bulb in his own mouth and noted the level of the water. Then he placed it in the patient's mouth. If the water was forced to a lower level, he decided that the patient had a fever. At the time when this thermometer was in common use, nothing was known about the spread of diseases by germs. Since the doctor probably did not bother to wash the bulb of the thermometer after it had been in the patient's mouth, the thermometer was a means of spreading infectious diseases.

Another disadvantage of Galileo's early thermometer was the error caused by changes in atmospheric pressure. The readings on two successive days could not be accurately compared; a change in the weather might cause an increase in atmospheric pressure that would, in turn, force the water higher up the tube even though there was actually no change in temperature.



Courtesy Taylor Instrument Co.

Fig. 13–2. A modern liquid thermometer.

Liquid Thermometers. Galileo's air thermometer was also very cumbersome. A thermometer that depends on the expansion of a liquid (for example, mercury) is much more convenient. Most modern thermometers are made of glass tubing. Running through the center of the tube is a hole whose diameter is about the same as that of a human hair; such tubing is called *capillary* tubing. (To see how small the hole in a thermometer tube is, wrap the stem of an old or cheap thermometer in heavy cloth and break it.) At one end of the tube is a thin-walled bulb of glass containing mercury or colored alcohol. The air in the tube above the liquid has been removed, and the top of the thermometer has been sealed by heating it. When the liquid in the bulb is warmed, it expands and rises in the tube. A scale to record the temperature is either etched on the glass or marked on the thermometer support.

Capillary tubing is used in a thermometer because, when even a very small amount of liquid is forced out of the bulb by a rise in temperature, the liquid will rise a relatively large distance in the fine tube. If a large tube were used, a change of one degree in temperature would force the liquid too short a distance up the tube to be read accurately.

In very cold climates mercury thermometers cannot be used outdoors during the winter because mercury freezes at 40° below zero. Alcohol thermometers are frequently used instead because alcohol freezes at a lower temperature. Usually the alcohol is colored with red or blue dye so that the liquid level in the stem can be easily seen.

Thermometer Scales. Every thermometer has a scale which indicates temperatures. The *Fahrenheit* and *centigrade* scales are the two in most common use. The Fahrenheit scale is used in English-speaking countries; the centigrade scale is used in other countries, and for most scientific work. Both these scales are shown in Fig. 13–3.

The Fahrenheit Scale. The scale for a Fahrenheit thermometer is made by first placing the thermometer in a jar of melting ice. When the mercury stops falling, a scratch is made on the stem at the top of the mercury column; this becomes the 32° mark of the thermometer. Then the thermometer is placed in boiling water, the new level of the mercury is noted, and the corresponding scratch made on the stem. This becomes the 212° mark of the thermometer. The space between these marks is divided into 180 equal parts, each representing one degree. More divisions of the same size can be used to extend the scale of the thermometer above 212° or below 32°.

This thermometer scale is called the Fahrenheit scale because it was devised by Daniel Fahrenheit, a German scientist. On this scale our body temperature is about 98.6°, ordinary room temperature is about 70°, and a really cold winter's day in the northern portion of the United States is about 20° below zero or −20°.

The Centigrade Scale. The centigrade scale is simpler and, for most purposes, more convenient than the Fahrenheit scale. On this scale the temperature of melting ice is zero, written 0° C., and the temperature of boiling water is 100°, written 100° C. The range between these two temperatures is 100 equal parts, or degrees. On this scale room temperature is about 20°, body temperature is about 37°, and a cold day may be about 30 degrees below zero, that is, −30°.

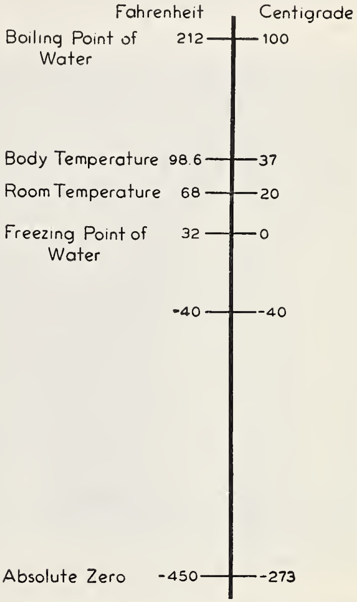


Fig. 13–3. Comparison of Fahrenheit and centigrade scales.

Demonstration 13–3. To Check the Boiling and Freezing Points on a Thermometer.

Place a laboratory thermometer that has a range from below freezing to above the boiling point of water in a jar of cracked ice. Let the bulb remain in the ice until the mercury no longer falls. What does the thermometer read? Is there an error? How much is it?

Next, support the thermometer in boiling water as shown in Fig. 13–4. After the mercury has stopped rising, read the temperature. Does the thermometer appear to be correct at this temperature?

Actually the boiling-point check will be accurate only if the barometric pressure is exactly 29.95 inches or 76 cm. of mercury. The reason for this is given in Chapter 17, where the effect of pressure on the boiling point of a liquid is discussed.

If we compare the Fahrenheit and centigrade scales in Fig. 13–3, we see that between the temperatures of melting ice and boiling water there are 180 Fahrenheit degrees and 100 centigrade degrees. This means that a Fahrenheit degree is smaller than a centigrade degree because more Fahrenheit degrees are needed to cover this temperature range. In fact, one Fahrenheit degree is equivalent to only $^{100}/_{180}$, or $^{5}/_{9}$, of a centigrade degree.

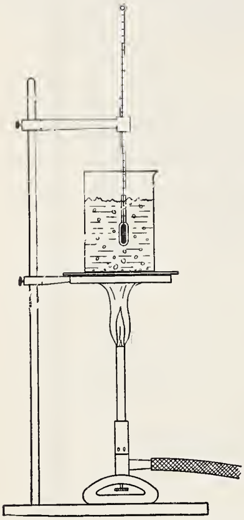


Fig. 13–4. Checking the boiling point on a thermometer.

Converting Fahrenheit Temperatures to Centigrade. Since the Fahrenheit scale reads 32° when the centigrade scale reads 0°, to change a Fahrenheit temperature to the corresponding centigrade temperature, we subtract 32 from the Fahrenheit temperature and then multiply the result by $^{5}/_{9}$. For example, if room temperature is about 68° F., what is the temperature on the centigrade scale?

To make the change, first subtract 32 from 68, which gives 36. Now multiply 36 by $^{5}/_{9}$; the result is 20° C.

Converting Centigrade Temperatures to Fahrenheit. To change a centigrade temperature to the corresponding Fahrenheit temperature, we must reverse the procedure. First we multiply the centigrade temperature by $^{9}/_{5}$, and then add 32 to the result. For example, if body temperature is 37° C., what is its temperature on the Fahrenheit scale?

First multiply 37 by $^{9}/_{5}$, which gives 66.6. Now add 32; the result is 98.6° F. Changing from one scale to the other may be accomplished by the use of the algebraic formula $\frac{F - 32}{9} = \frac{C}{5}$ or $C = {}^{5}/_{9}\,(F - 32)$, where C is the centigrade temperature and F is the corresponding Fahrenheit temperature.

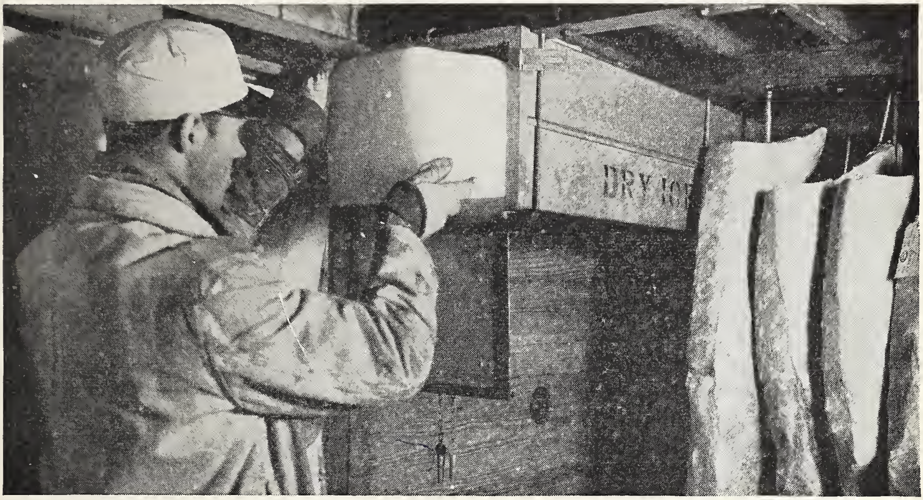
The Clinical Thermometer. The mercury level of an ordinary thermometer changes rapidly as the temperature changes. This is a disadvantage in taking body temperatures. When a person's temperature is taken, the thermometer should be read carefully and in a good light. Unless the mercury stays in place after the thermometer is removed from the patient's mouth, the temperature reading will be incorrect. To keep the mercury in place, clinical thermometers are made so that the inside passage in the stem is very narrow just above the bulb. When the mercury in the bulb is heated, it exerts sufficient force to push past this constriction and rise up the stem. When the mercury in the bulb cools and contracts, however, the column of mercury breaks at the constriction and is held in the stem, and a correct reading can be made. The thermometer can be reset by holding it in the hand and quickly snapping the wrist, which drives the mercury past the constriction into the bulb.

A clinical thermometer measures only a

$F = \frac{9}{5} C + 32$

small range of temperatures, usually from about 92° F. to 108° F. This type of thermometer should not be sterilized with hot water, as water hotter than 108° F. would expand the mercury enough to break the thin glass wall. Alcohol or formaldehyde, both good disinfectants, should therefore be used for sterilizing clinical thermometers.

Low Temperatures. In the northern part of the United States winter temperatures often fall below 0° F.; in the Midwest, temperatures as low as −30° F., or even lower, have been recorded. But the coldest inhabited place on earth is in Siberia, where a temperature of −94° F. has been recorded.



Courtesy Air Reduction Sales Co.

Fig. 13–5. Dry ice is used to cool refrigerator cars.

These, however, are by no means the lowest temperatures possible. Dry ice (which is solid carbon dioxide) has a temperature of −80° C. or −112° F. It is used to cool refrigerator cars, as shown in Fig. 13–5, so that meat and vegetables can be transported safely. It is also used to keep ice cream frozen.

Ordinary air liquefies at a temperature of about −200° C. by a process of compression and expansion. Liquid air is often used as a cooling agent in the laboratory since, once it is made, it remains at −200° C. until it accumulates enough heat to boil away.

Scientists have calculated that the lowest possible temperature is −273° C. (−459° F.), usually called the *absolute zero*. Theoretically, this is the point at which all molecular motion ceases. It is nature's zero and has never been quite reached by man. The nearest approach is about −272° C., the temperature of solid helium. Helium is, of course, a gas at ordinary temperatures. It becomes a liquid when cooled to −270° C., then a solid at −272° C.

High Temperatures. The highest recorded temperature for New York City is 102° F. and for Chicago, 105° F. Tunis, in North Africa, is one of the hottest places in the world; there the temperature has risen to 118° F. in the shade. But much higher temperatures than this are possible. Rocks, for example, melt at about 1100° C. Iron must be heated to 1500° C. before it will melt; the metal tungsten, to 3370° C. The temperature of the surface of the sun is about 6000° C. The surfaces of some stars are as hot as 30,000° C., and it is possible that their centers may be over one million degrees centigrade. Scientists have not been able to find any theoretical limit to high temperatures.

If substances are heated to sufficiently high temperatures, they give off light. Thus, when an iron bar is heated sufficiently it begins to glow red-hot; and if it is heated still more, it gradually becomes yellow-hot, and finally white-hot. In other words, color changes with temperature, if the temperature is high enough. By using the color-temperature relationship, some useful thermometers have been made for measuring high temperatures; for example, the temperature of an open-hearth furnace is measured in this way.

Demonstration 13–4. Temperatures in the Bunsen Flame.

Copper melts at 1050° C. Heat the tip of a piece of copper wire in a Bunsen flame until a tiny globule of molten copper forms on the tip of the wire. Shake the wire and molten copper will drop off the tip.

Repeat this experiment with a piece of iron wire, and note how the color of the wire changes as its temperature increases. You will find that the flame is not hot enough to melt the iron. Approximately, what is the temperature of a Bunsen flame?

It is interesting to note that although temperatures in the universe range from −273° C. to over a million degrees centigrade, the temperature of man's body must remain within three or four degrees of 37° C. or he may die. Since this range is so small, it is truly remarkable that early man ever survived and developed in a universe where there are such extremes of temperature.

THINGS TO REMEMBER

The *first thermometer* was made by Galileo. He used the expansion of air to measure temperature.

The *most common accurate thermometers* in use today employ an expanding liquid (mercury or alcohol) to measure temperature.

On the *Fahrenheit* scale the temperature of melting ice is 32° and the temperature of boiling water is 212°.

On the *centigrade* scale the temperature of melting ice is 0° and the temperature of boiling water is 100°.

A Fahrenheit *degree* is equivalent to $5/9$ of a centigrade degree.

To change a *Fahrenheit* temperature to the corresponding *centigrade* temperature, subtract 32 from the Fahrenheit temperature and then multiply the result by $5/9$.

To change a *centigrade* temperature to the corresponding *Fahrenheit* temperature, first multiply the centigrade temperature by $9/5$ and then add 32 to the result.

The lowest temperature possible is −273° C. This temperature is called *absolute zero.*

QUESTIONS

A

1. Describe the construction and operation of Galileo's thermometer.
2. Describe the construction and operation of a modern liquid thermometer.
3. What are the freezing and boiling points of water on (*a*) the Fahrenheit scale; 32, 212 (*b*) the centigrade scale? 0, 100
4. What is the lowest possible temperature? What is it called? absolute zero -273°C
5. How does liquid air differ from ordinary air?
6. What happens to the motion of the molecules of a substance when it is heated?
7. Which is at the higher temperature, a yellow-hot or a white-hot piece of iron?
8. How does a clinical thermometer differ from an ordinary mercury thermometer?
mercury does not drop unless forced down.

B

9. On a hot day in Chicago the temperature sometimes reaches 100° F. What temperature is this on the centigrade scale? 37.7

10. Determine which of the following statements are true and which are false. Then correctly reword the false ones.

(*a*) When the temperature of a substance is increased its molecules move ~~slower~~ faster.

(*b*) A clinical thermometer has a narrow constriction in the inside of its stem.

(*c*) Water boils at 212° C.

(*d*) Water freezes at 0° C.

(*e*) The freezing point of water is absolute zero.

11. What Fahrenheit temperature corresponds to 60° C.?

12. A mixture of ice and salt in an ice-cream freezer produces a temperature of 0° F. What is this temperature on the centigrade scale?

13. What Fahrenheit temperature corresponds to −100° C.?

14. The highest temperature in summer in a certain city is 108 Fahrenheit degrees above the lowest temperature in winter. What is this range of temperature in centigrade degrees?

15. What are the temperatures of dry ice (−80° C.) and liquid air (−200° C.) on the Fahrenheit scale?

16. Calculate the centigrade temperature corresponding to −40° F.

17. The melting point of sulfur is 114.5° C. What is the melting point of sulfur on the Fahrenheit scale?

18. Rocks melt at about 2000° F. What is this on the centigrade scale?

19. The temperature of the earth rises about 1° C. for every 100 feet of depth. Find the approximate temperature at a depth of 25 miles.

PROJECTS

1. *To Draw a Graph That May Be Used to Change Temperature Scales.* Place two accurate laboratory thermometers, one Fahrenheit and one centigrade, side by side on a table. After about five minutes read and record the temperatures indicated by both thermometers. Repeat this procedure with both thermometers in a jar of melting ice, and then with both thermometers in a large jar of hot water. Using the three pairs of temperatures you have obtained, draw a graph by plotting the centigrade temperatures along the vertical axis and the Fahrenheit temperatures along the horizontal axis. This graph can be used to change temperature scales. For example, from it find out what Fahrenheit temperature corresponds to 30° C., 40° C., and 60° C. You can check your result by calculation, using the method described on page 122.

2. *Some Effects of Low Temperature.*

(*a*) Hold the bulb of a thermometer in close contact with a few small pieces of dry ice. What happens to the liquid in the thermometer? *Caution:* Wear gloves when handling dry ice; it can freeze your fingers very quickly.

(*b*) Fill a small match box with mercury and surround the bottom, sides, and top with crushed dry ice (carbon dioxide). Mercury should be handled over a large dish or tray so that it will not be spilled, since it is nearly impossible to pick it up. Hold a long pencil vertical in the middle of the mercury as shown in Fig. 13–6 until the mercury is frozen solid. Now break away the box and you have a mercury hammer. What eventually happens to your hammer? *Note:* As mercury is a poisonous substance, wash your hands thoroughly after handling it.

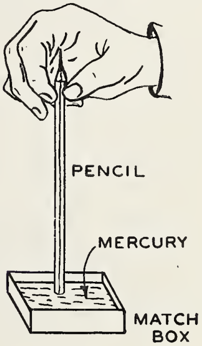


Fig. 13–6. Making a mercury hammer. The box and mercury are covered with dry ice until the mercury is frozen.

Fahrenheit ° smaller than centigrade

Chapter 14

WHAT IS HEAT?

You hardly need to be told that heat from fire is probably the most important factor in modern civilization. Without it living would be not only uncomfortable but also primitive. In the home, heat gives us comfort. The coal or wood fire on the hearth, the oil fire in the basement, and the gas stove in the kitchen all contribute to our pleasant way of life. In industry, the heat of a blast furnace melts the iron needed to make steel. In transportation, locomotives, automobiles, planes, and ships depend upon heat for their operation. These are obvious examples of the various uses of heat. But do you realize that more than half our electricity is generated from the heat of burning coal?

Heat may be obtained from burning coal; a high *temperature* is also obtained from burning coal. What, then, is the difference between heat and temperature? This is an important question.

Let us consider the temperature of, and the heat in, a cupful and a pailful of boiling water. If a thermometer is placed in the cup and then in the pail, it will register the same temperature, 100° C. But does each vessel contain the same amount of heat? No, the water in the pail contains the greater amount of heat. Clearly there is some factor besides temperature that determines the amount of heat in the water. This factor is *weight*.

Units of Heat. Since the heat in a body depends upon its temperature and its weight, the unit of heat includes both these factors. One unit of heat is called a *calorie*, which is the quantity of heat needed to raise the temperature of one gram of water one degree centigrade.

Another common unit of heat is the *British Thermal Unit*, usually abbreviated *B.T.U.* or *B.t.u.* In this unit the quantity of water is one pound and the rise in temperature is one degree Fahrenheit. With this information state the definition of a B.T.U.

The B.T.U. is a much larger unit than the calorie. A one-pound weight is about 500 times as heavy as a gram weight, and one degree Fahrenheit is about half the size of one degree centigrade. Therefore one B.T.U. is about $500 \times \frac{1}{2}$, or 250 times as large as one calorie. To be accurate, 1 B.T.U. = 252 calories.

Scientists usually measure heat in calories, but the heat value of fuels is usually measured in B.T.U.

How Heat Is Measured. Suppose we wish to find how much heat is needed to raise the temperature of *one* pound of water *twenty* degrees Fahrenheit. It is obvious that twenty times as much heat is needed as to raise the temperature of one pound of water one degree Fahrenheit. In other words, twenty B.T.U. are needed.

Now suppose we wish to raise the temperature of *five* pounds of water *one* degree Fahrenheit. Five B.T.U. are needed, or five times as much heat as is required to raise the temperature of one pound of water one degree Fahrenheit.

Now let us combine these two ideas to solve a more difficult problem: How much heat is required to raise the temperature of 20 pounds of water from 60° F. to 140° F.?

The temperature of the water is to be raised 140 — 60, or 80 degrees. To heat one pound of water through 80 degrees requires 80 B.T.U. Therefore to heat 20 pounds of water through the same number of degrees requires 80 × 20, or 1600 B.T.U.

The equation for solving this problem is

$$\begin{aligned}\text{Heat} &= \text{wt. of water in pounds} \times \text{change of temp. in degrees F.}\\ &= 20 \times 80\\ &= 1600\ \text{B.T.U.}\end{aligned}$$

Similarly, if a known weight of water cools through a given number of degrees, we can calculate the amount of heat given out. If the weight of the water is given in grams and the temperature change in degrees centigrade, the heat will of course be measured in calories. For example:

How much heat is lost by 500 grams of water as it cools from its boiling point to 20° C.?

$$\begin{aligned}\text{Heat loss} &= \text{wt. of water} \times \text{temp. change}\\ &= 500\ \text{g.} \times (100 - 20)^\circ\ \text{C.}\\ &= 40{,}000\ \text{calories}\end{aligned}$$

Heating of Different Substances. If we heat equal weights of different substances, we find that their temperatures rise at different rates even though they receive heat at the same rate. This may be observed by heating equal weights of water and sand, and recording the rises in temperature.

Demonstration 14–1. To Show That Sand Heats Faster than Water.

Pour sand about an inch deep into a beaker. Find the weight of the sand. Now pour an equal weight of water into a similar beaker. Place each beaker on a tripod on which rests a wire gauze. Put a thermometer in each beaker and read the temperature of the water and of the sand.

Adjust the flames of two burners so that they are small and of the same size. Now put a burner under each beaker and stir the sand vigorously during the heating. Do you know why you should stir it? Read the temperature of the sand at intervals of about ten degrees up to 90° C. Each time you read it, read also the temperature of the water after stirring it.

The temperature of the sand rises much more rapidly than that of the water. Or, expressed another way, less heat is needed to raise the temperature of the sand through a certain number of degrees than is needed to raise the temperature of the water through the same number of degrees. Hence, *the amount of heat in a body depends not only on its weight and temperature but also on the nature of the substance.*

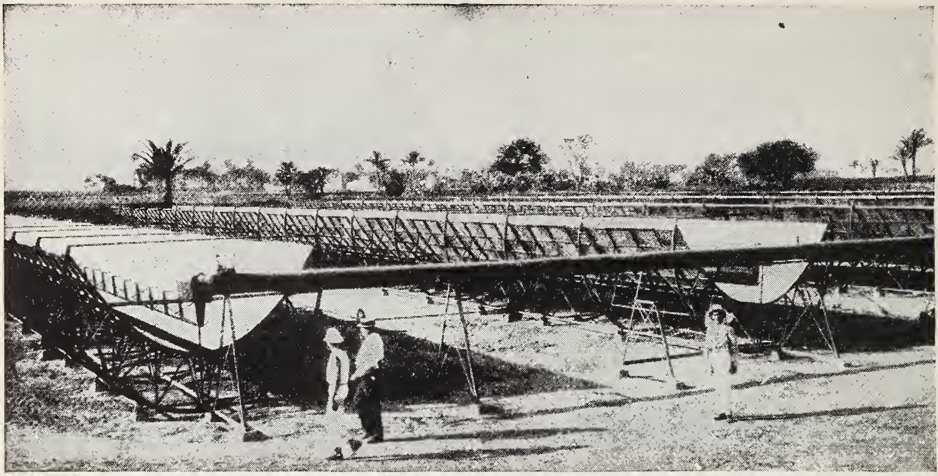
Most substances heat faster than water. On a hot summer day, for example, dry land is heated by the sun to an uncomfortably high temperature, and people flock to the seashore to be cooled by the breezes blowing in from the sea.

HOW HEAT IS OBTAINED

Since we are so dependent on heat, it is not surprising that man has tapped several sources of heat energy and is always looking for others. Our main supply of heat energy comes from the sun. Other important sources are combustion and electricity. Still another source, heat from the nuclei of atoms, will undoubtedly become increasingly important in the future.

1. **Heat from the Sun.** The sun is by far the most important source of heat, since all life on the earth depends upon it. If we received no heat from the sun, the temperature of the earth would fall close to absolute zero, −273° C., and neither plant nor animal life could exist.

Although the sun is an almost inexhaustible source of heat energy, man has scarcely begun to tap it for his own use. There is no satisfac-

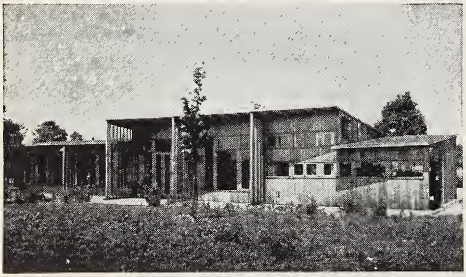


Smithsonian Institution

Fig. 14–1. An early experiment in capturing the sun's heat made use of concave mirrors to focus the sun's heat on water pipes running down the center of the trough-like mirrors.

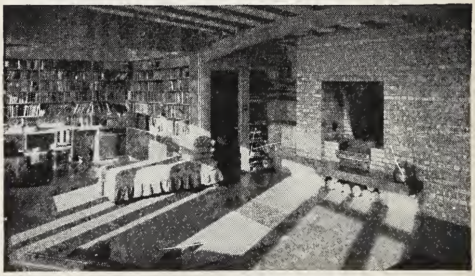
tory way of trapping and storing the sun's heat, and most of it is dispersed through the atmosphere and lost. Nature is far ahead of man in this respect, for she has solved the problem of storing the sun's energy. As we shall see in later chapters, coal and oil are storehouses of solar energy. If man could use all the sunlight that falls on the earth, he would have no need for coal or oil or atomic energy. Even the sunlight that falls each year on a thousand square miles of land (an area less than that of Rhode Island, the smallest state) would supply as much energy as the total annual consumption of coal.

Scientists are trying to find ways by which the sun's heat can be used to run machines. The sun's heat can be focused so that it can boil water, and the steam can be made to run



Courtesy Hedrich-Blessing Studio

Fig. 14–2A. Southern view of a solar house designed by George and William Keck. The large windows allow maximum sunlight to enter the house in winter, while the wide overhang of the roof shades the rooms in summer.



Courtesy Hedrich-Blessing Studio

Fig. 14–2B. Living room of the solar house shown in Fig. 14–2A. This photograph, taken at noon in midwinter, illustrates the complete penetration of sunlight into the house.

an engine. But the sun's heat is not obtained continuously. The sun shines only by day, and even during the day the heat is not available when the sun is obscured by clouds. So the big problem that faces the solar scientists is how the sun's heat can be stored. No satisfactory solution has yet been found.

Much progress, however, is being made on solar-heating systems in houses, and such systems are already being used extensively in Florida, California, and many of the southern states, and to a lesser extent in some of the northern states.

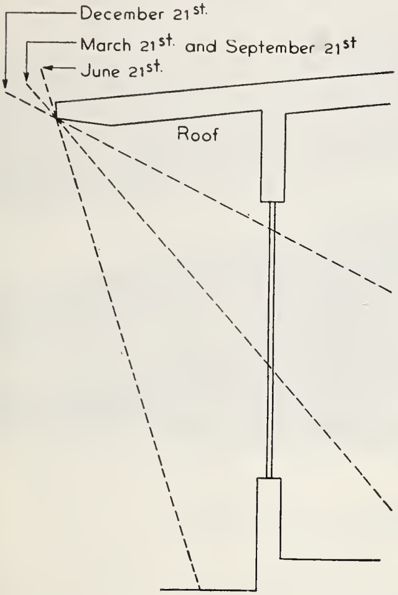


Fig. 14–3. Sun angles. This diagram shows how a roof with a long overhang allows maximum sunlight to enter the house in winter but cuts off entirely the direct rays of the sun in summer. The sun angles illustrated are those found in the northern United States.

To make maximum use of the heat from the sun's rays, two principal methods have been developed. Houses designed specifically for solar heating are built with large windows facing south and with wide eaves. The large windows permit as much sunlight as possible to penetrate inside during the winter months. The wide eaves shade these windows in the summer. This type of architecture takes advantage of the fact that the sun's rays reach us at a smaller angle in the winter than they do in the summer, as shown in Fig. 14–3.

The second method of solar heating depends not on the type of architecture but on the installation of a sun trap on the roof of any building. Such sun traps are constructed of panes of glass so arranged as to absorb as much heat as possible from the sun's rays and to use it in heating air which is circulated through the trap. On sunny winter days, even in the northern states, it has been found that the sun trap is capable of raising the temperature of the air passed through it by as much as 110 F°. When hooked into the thermostatic controls of the regular heating system, this sun-heated air may be used either for heating the home or, when the house is already warm enough, for preheating the hot-water supply. Actual tests conducted on a

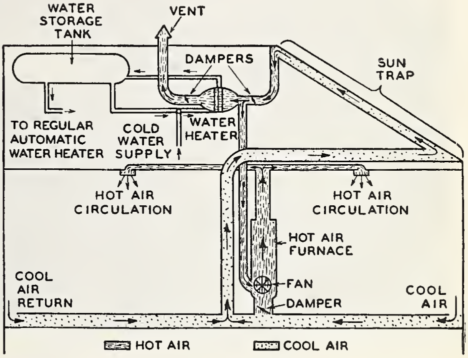
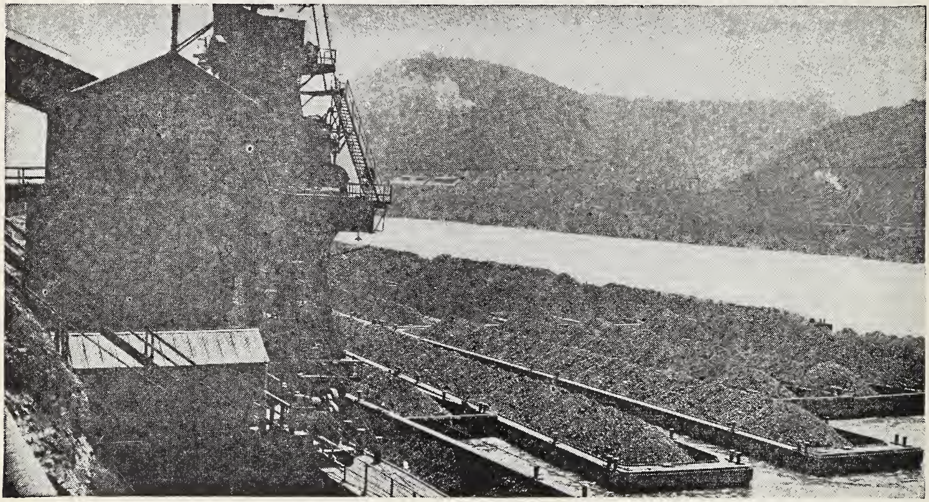


Fig. 14–4. Air strongly heated in a sun trap placed on the roof can be used in conjunction with the regular heating system to help heat the house or can be by-passed from the heating ducts to a water heater in the attic. (*Adapted from a diagram in* Architectural Forum, *February, 1947.*)

conventional house with a sun trap installed on the south slope of the roof indicate that fuel savings of 20 percent are already possible and that in climates having considerable winter sunshine savings of 50 or 60 percent may be achieved.



Courtesy Bituminous Coal Institute

Fig. 14–5. Coal is transported by barges to a plant where it is converted into coke and coal gas, both of which are important sources of heat of combustion.

Heat from Combustion. Most of the heat we use today is obtained by burning fuels. When a fuel such as coal or gasoline is burned, heat is produced. This burning is called *combustion*. There are many examples of it. In an automobile, the combustion of gasoline provides the heat needed to generate power to run the car. In a steam engine, the combustion of coal supplies the heat to produce the steam in the boiler, which, in turn, drives the engine.

Since combustion is one of the most important sources of heat, we might well ask whether all fuels give off the same amount of heat when they are burned. Actually they do not; some fuels produce more heat than others. The number of B.T.U. released when one pound of a substance is completely burned is called its *heat of combustion*. In the case of gases, however, the heat of combustion is usually expressed as the number of B.T.U. released when *one cubic foot* of the gas is burned. The following table gives the heat of combustion of some common fuels:

Substance	*Heat of Combustion*
Gasoline	18,700 B.T.U. per lb.
Hard coal	14,000 B.T.U. per lb.
Wood	8–9,000 B.T.U. per lb.
Water gas	530 B.T.U. per cu. ft.
Coal gas	600 B.T.U. per cu. ft.
Natural gas	1,000 B.T.U. per cu. ft.

Let us consider for a moment the heat of combustion of hard coal. When one pound of coal is completely burned, enough heat is released, as shown by the above table, to raise the temperature of 14,000 pounds of water one degree Fahrenheit. Similarly, when one cubic foot of natural gas is burned, enough heat is released to raise the temperature of 1,000 pounds of water one degree Fahrenheit.

Coal and natural gas are in greatest supply in western Canada, but industrial Ontario uses the coal of nearby Pennsylvania. Pipe lines from Alberta's natural gas reserves now give Canada an inexpensive way of transporting fuel to industrial centers.

Heat from Electricity. Some of the heat that we use in our homes and in industry comes from electricity. When an electric current flows through a special type of wire, a great deal of heat is produced. Many kitchen stoves and small electric heaters, such as toasters and waffle irons, and, in some cases, even houses are heated by electricity. Electricity is considered at some length in Chapters 35 and 36.

Nuclear Energy. Man has recently discovered that heat can be obtained by splitting the nuclei of atoms. Such heat is called *atomic* or *nuclear energy*. It is discussed in Chapter 58. Nuclear energy may in time become one of our commonest sources of heat and may to a large extent replace coal and oil.

4. **Heat from Friction.** Heat may also be produced by rubbing two rough surfaces together, a process called *friction*. As we learned in Chapter 1, friction was the means by which early man obtained the heat to start a fire. This source of heat is no longer very useful to us; in fact, in the operation of machinery friction must be overcome to some extent to avoid trouble. For instance, unless the moving parts of an automobile are oiled frequently, friction may produce so much heat that bearings will be burned out.

THINGS TO REMEMBER

A *British Thermal Unit* is the amount of heat needed to raise the temperature of one pound of water one degree Fahrenheit.

A *calorie* is the amount of heat needed to raise the temperature of one gram of water one degree centigrade. 1 B.T.U. = 252 calories.

The *heat in a body* depends upon its weight and temperature and on the nature of the substance. A pound of water has a greater heat capacity than a pound of any other common substance.

The *sun* is the most important source of heat, but this heat cannot be stored and is not used directly on a large scale for driving machinery.

The *heat of combustion of a solid* is the number of B.T.U. released when one pound of the substance is completely burned.

The *heat of combustion of a gas* is the number of B.T.U. released when one cubic foot of the gas is completely burned.

QUESTIONS

A

1. Define the terms *calorie* and *B.T.U.*

2. Name four ways in which heat can be obtained.

3. What is meant by the term *heat of combustion?*

4. Match each word in the left-hand column with the word it is most clearly related to in the right-hand column.

gram	thermometer
pound	calorie
temperature	B.T.U.
heat of combustion	coal

5. How much heat is needed to raise the temperature of one gram of water 30 centigrade degrees?

6. How much heat is needed to raise the temperature of 12 pounds of water one Fahrenheit degree?

B

7. How much heat is needed to raise the temperature of 100 grams of water 65 centigrade degrees?

8. How much heat is needed to raise the temperature of 15 pounds of water 30 Fahrenheit degrees?

9. How much heat can be produced by burning one ton of hard coal?

10. State fully what is meant when we say that the heat of combustion of gasoline is 19,000

B.T.U. per pound and that of the gas acetylene is 950 B.T.U. per cubic foot.

11. How much heat is required to raise the temperature of 100 pounds of water from its freezing point to its boiling point?

12. How much heat is given off by 1,000 grams of water cooling from the boiling point to the freezing point?

Chapter 15

EXPANSION

In the preceding chapter we said that a thermometer indicates temperature because the liquid in it expands when heated. As a matter of fact, almost all materials, whether solids, liquids, or gases, expand when their temperature is raised. The expansion of a long steel bridge on a hot summer day, for instance, is considerable and must be allowed for when the bridge is constructed.

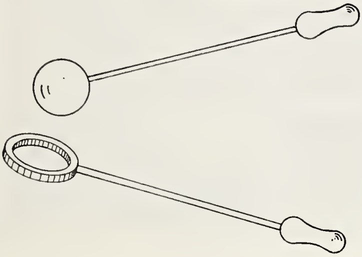


Fig. 15–1. Ball and ring to show expansion.

Expansion of Solids. Some solids, like glass, expand very little; others, like steel, expand much more. The expansion is usually so small, however, that we have to use special devices to detect it. One method is demonstrated in the following experiment.

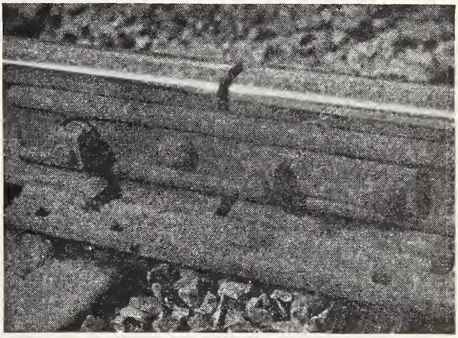
Demonstration 15–1. Expansion of a Solid.

This experiment requires an iron ball about an inch in diameter and an iron ring just large enough to allow the ball to pass through it. See Fig. 15–1.

Heat the iron ball for two or three minutes in a Bunsen flame; then try to force it through the ring. Since it will not pass through the ring, we know the ball has expanded as a result of the heating.

Now plunge the hot ball into a beaker of cold water and again try to pass it through the ring. The cooling of the ball restores it to its original size so that it can again pass through the ring.

Finally, heat both the ball and the ring. Notice that the ball can pass through the ring at all times when they are heated together, showing that the hole becomes larger as the ring is heated. An important application of this fact is described later in the chapter.

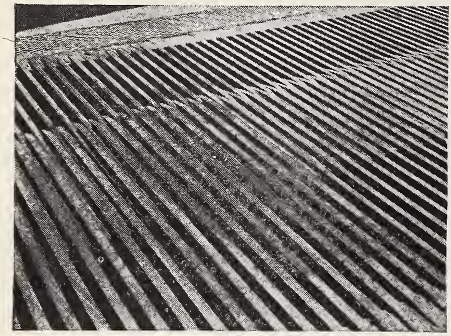


Cervin Robinson

Fig. 15–2. A gap between railroad rails allows for expansion of the metal.

Examples of Expansion. If you examine some railroad tracks, you will find that there is a small gap between the ends of the rails, as shown in Fig. 15–2. This gap allows for the expansion of the rails when they are warmed by the sun. A forty-foot rail, for instance, may be nearly half an inch longer in summer than in winter.

Engineers who build bridges must make allowance for expansion. Golden Gate Bridge at San Francisco, for example, is 4,200 feet long. Between a very cold day in winter and a very hot day in summer it may expand as much as three feet. If it did not have a device similar to that shown in Fig. 15–3B, it would buckle. The diagram shows the end of a bridge supported on rollers which allow the bridge to move back and forth as it expands and contracts. Interlaced fingerlike projections in the roadbed prevent a gap from being formed between the bridge and the road as the bridge contracts in the winter.



Courtesy The Port of New York Authority

Fig. 15–3A. A roadway expansion joint on the George Washington Bridge between New York City and Fort Lee, New Jersey.

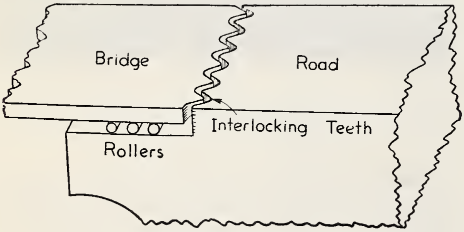
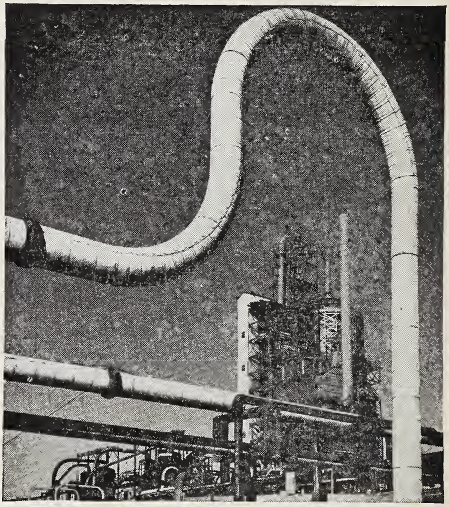


Fig. 15–3B. Diagram of one type of expansion device for a bridge.

Long steam pipes also have devices to allow for expansion. One such device is shown in Fig. 15–4; the loop in the pipe changes size as the pipe becomes longer or shorter, thereby reducing strains that might produce leaks.

Glass expands when heated, although its expansion is much less than that of steel. Glass is also a poor conductor of heat; it does not readily transmit heat from one side to the other. Therefore if hot water is poured rapidly into a thick glass jar, the inside becomes hot and expands before the heat reaches the outside. The force of expansion may break the jar. Glass coffee makers and laboratory beakers are therefore made of *thin* glass to reduce the likelihood of breakage by sudden changes in temperature. Often they are made of a special kind of glass, such as pyrex, that expands only about one-fifth as much as ordinary glass.



Courtesy Vachon, Standard Oil Co. (New Jersey)

Fig. 15–4. The expansion of a long steam pipe is absorbed in a bend or loop which can change shape without breaking.

The Thermostat. When a substance is heated, the amount of expansion depends not only on the temperature change but also on the nature and the amount of the material involved. If bands of two different metals are welded together to form a bimetal strip, the different rates of expansion of the metals can be used in fire alarms, thermostats, and other devices.

Demonstration 15–2. Expansion of a Bimetal Strip.

Obtain a strip of special material made from iron and brass pieces welded together as shown in Fig. 15–5. Heat the strip gently in a Bunsen flame. Which side of the strip expands more, the iron side or the brass?

Next, connect a battery and a bell to the strip as shown in Fig. 15–6. Heat the strip until its end touches the contact and makes the bell ring. What will happen as the strip cools?

This demonstration shows how one type of fire-alarm system operates. The heat of the fire causes the strip to curl. It thereby makes an electric circuit which rings the alarm. Fire alarms of this type are sometimes installed in warehouses, in holds of ships, or in other places where a fire might break out without being quickly discovered.

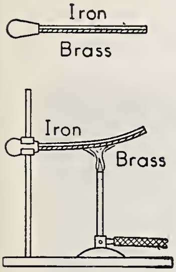


Fig. 15–5. A bimetal strip. The brass expands more than the iron when heated.

Other special strips of this kind are used in the thermostats that regulate the temperature of our homes, schools, and other buildings. One kind of thermostat is operated by a bar consisting of two pieces, one brass and the other steel, riveted firmly together. At ordinary indoor temperature, say 70° F., the two strips are the same length. If the temperature rises, both strips expand. The brass expands more than the steel, and the whole bar bends into a curve with the brass on the outside. The lower end of the brass strip breaks an electrical connection, thus shutting off the furnace. As the room cools, the strip straightens out and closes the switch that starts the furnace again. Such a thermostat will keep a room within a degree or two of any desired temperature.

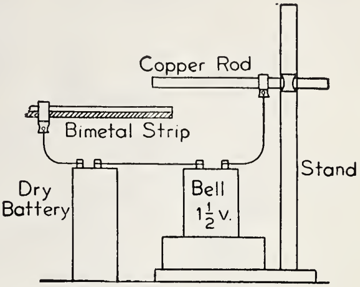


Fig. 15–6. When the bimetal strip is heated, it makes contact with the copper rod, the electric circuit is closed, and the bell rings an alarm.

Many inexpensive thermometers are made of bimetallic strips. The strip is arranged in a coil which winds up as the temperature rises and unwinds as the temperature falls. A pointer attached to the coil moves over a scale that indicates the temperature, as shown in Fig. 15–8A.

Contraction on Cooling. The early American settlers made a practical application of the principle of expansion of materials when they constructed an iron tire for a wooden wagon wheel. They made the tire a little smaller than the rim of the wheel. Then they heated it in a bonfire until it expanded just enough to be slipped around the wheel. They then dashed cold water on the tire. This caused the iron to contract on the wood with such force that the tire stayed in place without the use of nails.

Today when a steel tire is placed on the rim of a locomotive wheel, the tire is heated, fitted into place, as shown in Fig. 15–7, and then cooled. It fits tightly and does not slip even when the locomotive draws the heaviest trains. When the tire wears out, it can be removed and a new one put in its place without damage to the main part of the wheel. The next time you see a locomotive look at the big driving wheels and observe where the tire fits on the wheel.

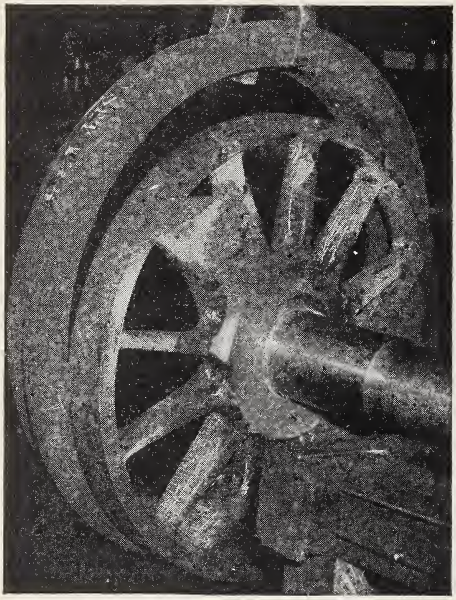
Steel rivets used for holding together the steel plates of bridges and ships are heated red-hot before being hammered into place. Each rivet has a head like that of a screw. The rivet goes through the plate and the end is flattened into another head. When the rivet cools, it contracts with tremendous force to make a strong joint.

Expansion of Liquids. Liquids expand more than solids, and the effects of liquid expansion are both striking and useful. The following demonstration shows that water expands considerably when heated.

Demonstration 15–3. Expansion of Liquid.

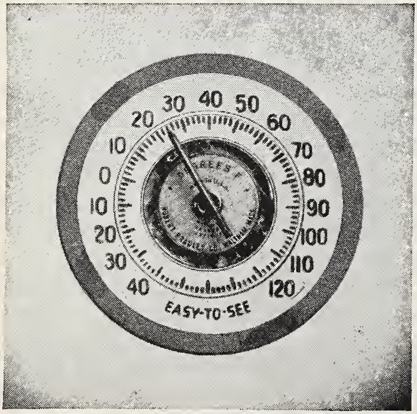
Fill a small glass flask with colored water and in the neck of the flask insert a rubber stopper and glass tube, as shown in Fig. 15–9. The liquid should be part way up the tube. Now dip the whole flask in boiling water, observing carefully what happens.

The level of the liquid in the tube first drops slightly and then rises rapidly as the



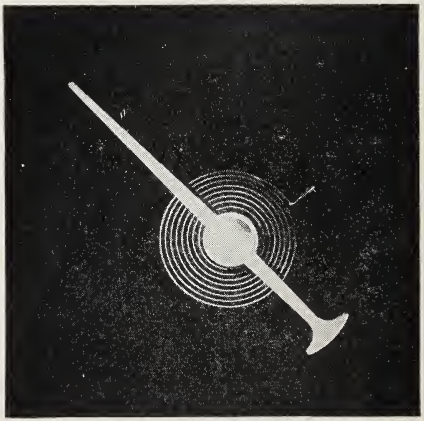
Courtesy American Locomotive Co.

Fig. 15–7. Fitting a hot metal tire to the rim of a locomotive wheel. When the tire cools, it will shrink to a tight fit.



Courtesy Robert Bradley Co.

Fig. 15–8A. A dial thermometer which uses a bimetal coil rather than a column of mercury for its operation.



Courtesy Robert Bradley Co.

Fig. 15–8B. The bimetal coil and pointer of a dial thermometer. As the coil winds up or unwinds because of temperature changes, the pointer is moved.

water in the flask is warmed. What caused the level of the liquid to drop? The drop was due to the expansion of the flask, which gets hot before the liquid does. As the liquid becomes hot, however, the flow is soon reversed in the tube. This happens because the expansion of the liquid is greater than that of the glass. Since liquids are held in solid containers, such as jars or bottles or cans, we observe only the *difference* between the two expansions. Because of this difference the mercury in the thermometer indicates changes in temperature. If the glass of the thermometer expanded as much as the mercury, the mercury would not rise in the stem.

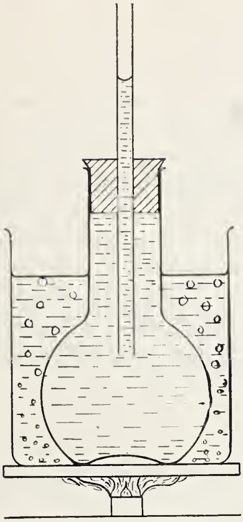


Fig. 15–9. Water expands when heated.

Perhaps you have noticed that bottles containing liquids such as ginger ale or cola drinks are never filled completely. The reason for this is that space must be allowed for the expansion of the liquid. If the bottles were filled to capacity, they might leak or even break if stored in the sun or near a radiator.

Expansion of Gases. Galileo's thermometer, you will recall, depended for its operation on the expansion of a gas. As a matter of fact, ① gases expand 20 times as much as mercury and 100 times as much as steel. Another peculiarity of gases is that ② they all expand by nearly the same amount when heated the same number of degrees. In this respect they differ considerably from liquids and solids.

Gases are composed of molecules, but the molecules occupy surprisingly little of the volume; in ordinary air, for instance, the molecules constitute only about one-thousandth of the volume and the rest is empty.

When the air in a container is heated, the speed of the molecules increases. The molecules therefore bombard the walls of the container harder and faster than before, which produces an increase in pressure. If the gas is in a container that expands easily, such as a balloon, heating does not materially increase the pressure of a gas but merely causes it to expand.

Cooling a gas produces the opposite effect; that is, the molecules slow down as the temperature of the gas falls, and the pressure decreases.

Demonstration 15–4. Collapsing a Tin Can by Cooling the Air Inside.

Heat a gallon tin can. Then quickly screw on a tight-fitting cover and play a stream of cold water over the can. The can collapses.

Why does the can collapse? Why are the walls pushed in? The air in the can expanded when heated and some of it escaped, so that the molecules left behind were spaced farther apart. When the cover was screwed on and the can cooled, the molecules inside slowed down and exerted less pressure on the walls of the container. As a result, the pressure of the atmosphere was great enough to cause the walls of the can to cave in.

Heating a Gas by Compression and Cooling by Expansion. When you use a bicycle pump vigorously to pump up a tire, the bottom of the pump becomes warm. The work you do and the heat produced by it are closely connected. Where does the heat come from? As the piston is pushed into the pump, it strikes against air molecules, making them move a little faster and thereby raising their temperature. *The work you do shows up as heat in the gas.* In other words, *work can be converted into heat.* In a similar way, heat is produced when the gas in a cylinder of a Diesel engine is compressed. This heat of compression causes the fuel to burn, an effect discussed in detail in Chapter 32.

On the other hand, if a gas is allowed to expand rapidly, it cools and absorbs heat from its surroundings. For instance, air that is allowed to escape rapidly from a bicycle tire feels much cooler than the surrounding air. This cooling effect is shown strikingly in the following demonstration.

Demonstration 15–5. Cooling a Gas by Expanding It.

Carefully open the valve of a tank of compressed carbon dioxide. Find the temperature of the escaping gas with a thermometer. What was the temperature of the gas? How does it compare with the temperature of the air?

Why has the gas cooled? The molecules of carbon dioxide in the tank are packed so close together that they exert a high pressure on the walls of the tank. Since the molecules are at room temperature, however, they are not moving exceptionally fast. When the valve is opened, the carbon dioxide molecules stream out, pushing against the air molecules. The air slows them down, thereby lowering their temperature. This process of cooling a gas by allowing it to expand is fundamental to the operation of the heat engines described in Chapters 31 and 32.

THINGS TO REMEMBER

Solids, liquids, and gases expand when heated and contract when cooled. Liquids expand more than solids, and *gases expand more than solids and liquids.*

Expanding solids can exert a great force; so can *contracting* solids.

Different materials expand *at different rates,* except that all gases expand at about the same rate.

Heating a gas either raises its pressure or makes it expand, or does both. *Cooling* a gas produces the reverse effect.

Compressing a gas *heats* it; *expanding* a gas *cools* it.

Gas pressure is caused by the bombardment of a surface by the rapidly moving gas molecules.

QUESTIONS

A

1. A suspended telephone wire sags more in the summer than in the winter. Why?

2. Does the hole in a metal plate become smaller or larger when the plate is heated?

3. Why are laboratory beakers made of thin glass?

4. What is a thermostat?

5. How does the motion of gas molecules in a closed vessel change when the gas is heated?

6. Does the air escaping from the valve of an automobile tire feel warmer or cooler than the surrounding air?

B

7. Long steam pipes frequently have a loop. Explain the purpose of the loop.

8. On what three factors does the expansion of a solid depend?

9. Why are rivets heated before being hammered into place?

10. Which metal when heated would be on the outside of the curve of a bimetal strip of iron and brass? Why?

11. How does a bimetal thermostat operate?

12. The cap of a cold and nearly empty milk bottle may be forced out of the bottle if the bottle is allowed to stand in a warm kitchen. What causes this?

13. If you fill the tires of your car in the cool morning before a long drive on a hot summer day, should you fill them to a higher or lower pressure than normal? Explain.

14. Name two ways in which the expansion of gases differs from the expansion of solids.

15. Air molecules in a balloon move with the same speed as free air molecules at the same temperature. How can the molecules inside a balloon be made to exert a greater pressure than those outside?

16. Some gas in a cylinder is suddenly compressed by a piston. The compressed gas is then released through a small hole in the top of the cylinder. Explain any temperature changes that take place and give a reason for these changes.

PROJECTS

1. *To Construct a Simple Temperature Regulator.* Fill a large test tube with salt water. Into the top of it press a two-hole rubber stopper containing a small-bore glass tube and a copper rod as shown in Fig. 15–10. Connect a dry cell and a 1.5-volt flashlight bulb as shown. Now if the water is heated, it will rise up the glass tube and turn on the light. What might the device be used for?
2. *To Show That Air Contracts on Cooling.* Cook an egg until it is hard boiled and then remove the shell. Place a milk bottle in hot water for five minutes or so. Remove the bottle from the water and place the egg in the mouth of the bottle so that it acts as a stopper. Notice that the egg is slowly sucked into the bottle. Can you explain what has happened?

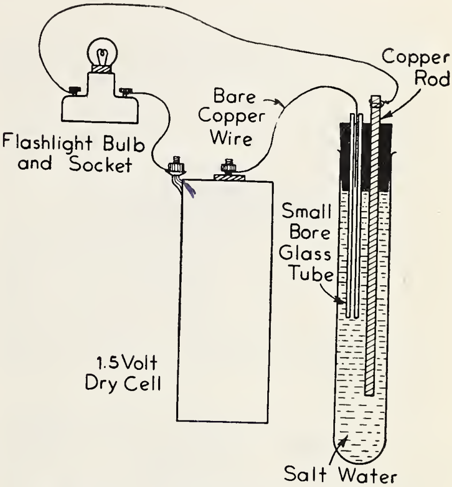


Fig. 15–10. A simple temperature regulator.

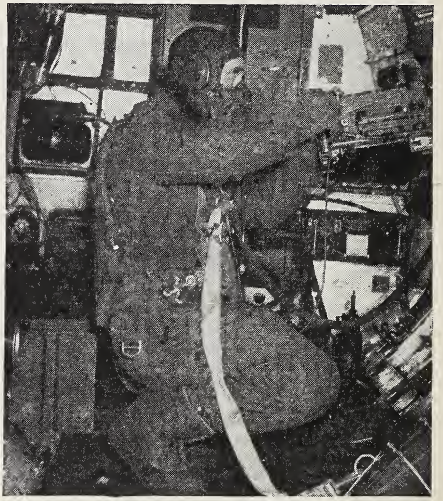
Chapter 16

HOW HEAT TRAVELS

How does heat travel along an iron poker? How does a hot-water heating system work? Why are desert regions hot? What is an ocean current? How does the sun's heat reach the earth? Why are houses insulated? The answers to all these questions involve the *transfer of heat*. The questions themselves also suggest that heat can travel in different ways. The passage of heat through an iron poker is quite different from the flow of heat in an ocean current; and this, in turn, is quite different from the transfer of the sun's heat to the earth.

Heat can be transferred in three different ways: *conduction*, *convection*, and *radiation*. We shall consider each method in turn. Since we cannot see heat, we can tell when it is traveling only by the effects it produces. For instance, when heat moves from one object to another, a cold object may become warmer, a solid may melt, or a liquid may turn to vapor.

Conduction. If one end of an iron rod is put into a fire, the other end soon becomes uncomfortably hot. How does the heat travel? Certainly there is no flow of hot particles of iron, because iron is a solid. The fire makes the molecules of the iron vibrate faster at the heated end of the rod. These fast-moving molecules collide with the slower, cooler molecules nearby, causing them to vibrate faster. These, in turn, strike against the next ones, until eventually all the molecules of the bar are moving more rapidly than before, and the whole bar is warm. In other words, the *heat spreads from molecule to molecule through the bar*. This method of transmitting heat by molecular vibration is called *conduction*.



Courtesy U.S. Air Force

Fig. 16–1. This insulating suit is worn to protect airmen against the cold at high altitudes. Notice the heavy gloves used for handling the metal equipment. Why are they necessary?

All metals are good *conductors* of heat. Polar explorers know this, and in cold weather they always handle metals, such as a gun barrel, with gloved hands. If a person touched the metal with his bare hands, he would be in danger of becoming frostbitten because the metal would conduct the heat away from his hands very rapidly.

Nonmetals—such as wood, glass, water, and air—are, in general, poor conductors, or insulators. Ordinary glass is such a poor conductor that a piece can be held safely with the fingers only a few inches from a red-hot part of it. Air is used as a heat insulator in many different ways. Storm windows, for instance, hold a layer of air between their panes and those of the regular windows; blankets and woolen clothing hold air entangled in their fibers and protect us from the cold. Asbestos fibers are used in stoves and fire curtains to reduce the danger of damage from fire.

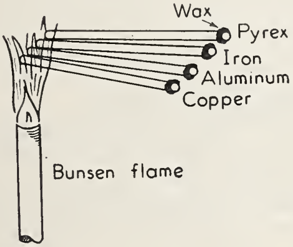


Fig. 16–2. Testing the conductivity of various materials.

Rocks are poor conductors. Only the parts of the rock near the surface are heated by the sun, the underlying layers remaining almost unaffected. It follows that only the surfaces of rocks expand. The expansion sets up strains that crack the rock surfaces, breaking the rocks to smaller fragments. As we have learned, this process is known as weathering.

That all materials do not conduct heat equally well is shown in the following demonstration.

Demonstration 16–1. Conductors and Insulators.

Arrange rods of copper, aluminum, iron, and pyrex glass as shown in Fig. 16–2. On the end of each place a bit of paraffin wax. Heat all the materials at the same time with a Bunsen flame. Notice the rod on which the paraffin melts first; this is the best conductor. Which is the best conductor? Which is the poorest? How would you explain the difference in terms of molecular motion?

The best conductor of heat is silver; copper is a close second. Both metals are also good conductors of electricity. Gases and most liquids are among the poorest conductors of heat. Can you tell why?

Another interesting experiment on conduction can be performed by lowering a piece of copper gauze over the flame of a Bunsen burner as shown in Fig. 16–3. The flame is stopped by the gauze. Why? Does the gas pass through the gauze? Apply a lighted match above the gauze and show that the gas burns. Why did it not burn at first? The reason is that the metal gauze conducts the heat of the flame away so fast that any gas which passes through the gauze is cooled so much that it does not burn.

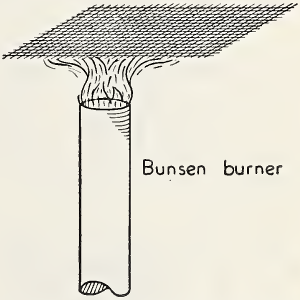


Fig. 16–3. An open mesh of copper gauze stops a Bunsen burner flame because of conduction.

This experiment led to the important invention of the Davy safety lamp, which is used in coal mines (see page 214).

Convection. If you hold your hand some distance above the flame of a Bunsen burner, it feels hot. A space containing air separates your hand from the flame. Your hand is therefore not heated by conduction, because air is a poor conductor. Instead, the flame heats the air which expands and rises and then heats your hand. In other words, an air *flow*, or current, is formed. This method of heat transfer is called *convection.*

Actually the Bunsen flame has created a miniature hot wind, which is simply a convection current caused by hot gas flowing from a hotter to a cooler region. Convection in a gas can be illustrated by the following demonstration.

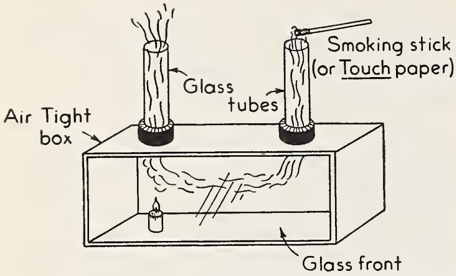


Fig. 16–4. A smoke box for showing convection currents in air.

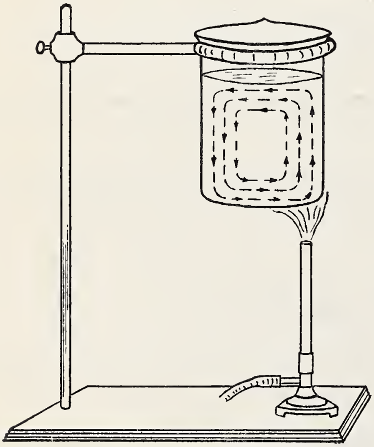


Fig. 16–5. Convection currents in a beaker of water.

Demonstration 16–2. Convection in a Gas.

Obtain a box with two glass chimneys and a glass front, as shown in Fig. 16–4. Place a lighted candle under one chimney. Now hold a piece of smoking punk first over one chimney and then over the other. How would you describe the motion of air in each of the chimneys?

The air in one chimney is warmed by the candle flame, expands, and rises up the chimney. Cool air goes down the other chimney, is warmed, and rises in turn. Thus we have a convection current set up in the air by which the heat from the candle is transferred up and out the chimney by the motion of heated air.

Before large ventilating fans were used, coal mines were supplied with fresh air in the same way. A fire was built at the bottom of one shaft, thus creating a convection current and drawing fresh air into the mine through other shafts. This method was dangerous because explosive gases released from the coal were sometimes ignited by the flame.

Precisely the same kind of flow occurs in water when it is heated. The direction of the arrows in Fig. 16–5 shows the direction of flow of such currents in a beaker of water. However, a convection current in a liquid can be shown more clearly by the following method.

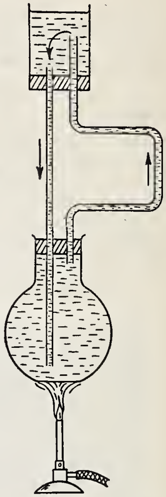


Fig. 16–6. Convection currents of water in a miniature hot-water heating system.

Demonstration 16–3. A Miniature Hot-Water Heating System.

Bend some pyrex tubing into the shape shown in Fig. 16–6. Fill the apparatus with water and put some red ink into the top container. Heat the bottom of the flask. What happens to the red ink? What happens to the water in the side loop?

The heat from the flame warms the water in the flask, making it expand. The warm water is less dense than the cold water in the straight tube, and therefore rises; the cold water moves in to take its place. The cold water is heated in turn and moves up, thus producing a continuous circulation or *convection current*. In this way heat is carried by the moving water to all parts of the system.

An ocean current is simply a convection current on a grand scale. The Gulf Stream, for instance, travels for hundreds of miles across the Atlantic Ocean and carries heat from the tropical regions of Central America to northwest Europe. Ocean currents have a considerable influence on the climate of a country. Without the Gulf Stream the climate of the British Isles and Scandinavia would be much colder than it is.

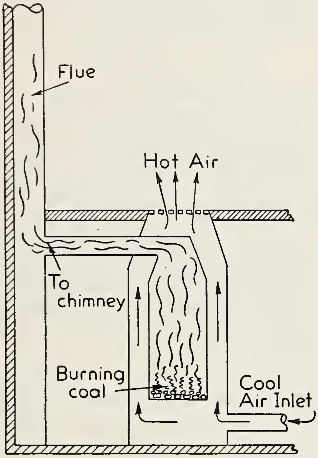


Fig. 16–7. Diagram of a simple hot-air furnace.

House Heating Systems. Convection currents are commonly used in heating houses. There are two such systems, *hot-air* and *hot-water*. In both systems the furnace provides heat that is distributed by convection to all parts of the house.

Hot-Air Heating System. The furnace for this type of heating system has a firebox in the center; a connecting chimney carries off the fumes from the burning coal. Surrounding the firebox is a metal shell, as shown in Fig. 16–7, through which air flows and is heated. This hot air is carried by large pipes to the rooms of the house. The air circulates through the rooms, gradually losing heat, and eventually flows down return pipes to the furnace to be reheated. This system of heating is relatively inexpensive to install and is quite satisfactory for small houses.

Hot-Water Heating System. Another heating system makes use of hot water instead of hot air. Iron pipes in the top of the furnace contain water which is heated by the fire. The hot water rises through pipes to radiators in the rooms of the house, where it gives up its heat to the air of the room; then it returns by other pipes to the furnace to be reheated. An expansion tank, frequently placed in the attic, is generally used to take care of the expansion of the water as it is heated. Sometimes a small circulating pump is installed in the system to help the flow of water. A hot-

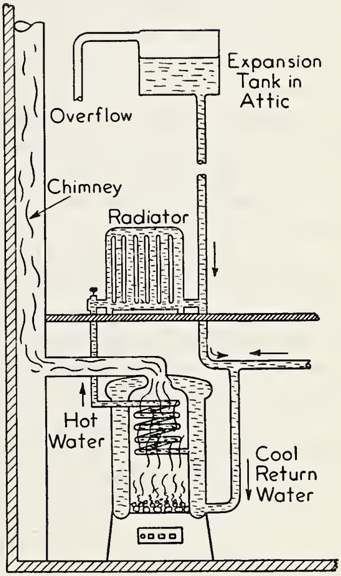


Fig. 16–8. Diagram of a simple hot-water furnace heating system.

water heating system is shown in Fig. 16–8.

The radiators, which are heated by the hot water, give up their heat to the air by conduction. The air then circulates by convection. There is still another method, however, by which heat leaves the radiator, that is, by *radiation*.

Radiation. Place your hands *under* an electric light bulb. How does the heat reach your hand from the glowing filament? It cannot be by convection currents since convection currents *rise* from heated bodies. Nor can it be by conduction, for air is a poor conductor of heat. Actually, the heat travels by radiation. Indeed, experiments show that this type of heat travels easily through a vacuum and that it can be reflected by mirrors. In fact, it behaves very much like light, and it is called *radiation* or *radiant heat.*

This is how the sun heats the earth. The sun radiates an enormous amount of heat into space in all directions. Only a tiny fraction of this heat hits the earth, however, the rest being wasted in space. Yet all the life on the earth depends on the small fraction of the sun's heat that strikes it. Green plants use sunlight to produce their food, and these plants are the source of both food for man and coal for his engines. We shall see in a later chapter that climate is also dependent on the sun's radiant heat.

Radiation is reflected from white or shiny surfaces and is absorbed by dark surfaces. This may be observed by putting a square of white cloth and a square of black cloth on clean snow in sunlight. The white cloth reflects the radiant heat and remains on the surface; the black cloth absorbs the heat, the snow beneath melts, and the cloth sinks into it. For the same reason dark leaves quickly sink beneath the surface of snow, and bits of dirt or ashes melt their way through the ice on a sidewalk and help to break up the slippery surface even on a very cold day.

Conversely, black objects radiate heat more readily than shiny ones. For this reason the radiators in a room should be painted black if they are to heat a room efficiently. The hotter an object, the greater the radiation from it. The sun, for instance, has a surface temperature of over 6000° C., which explains the vast amount of heat it radiates.

Scientists now believe that when heat is transferred from place to place by radiation, the heat energy is first changed into waves like light. These waves move through space and are changed back into heat only when they are absorbed. Thus heat coming from the sun warms the earth, which absorbs it, but does not appreciably warm the air or empty space through which it passes.

Demonstration 16–4. Absorption of Heat.

Hold a thermometer in the sooty part of the flame of burning camphor until the bulb is coated with a *thin* black layer of carbon. Take care not to get the thermometer too hot. Then place this thermometer and a similar but uncoated one side by side in a room out of the direct sunlight. After a few minutes read the temperatures; then place the instruments in sunlight. Read them every three minutes for a 15-minute period. What is the maximum temperature difference?

The two thermometers should read the same in the absence of direct sunlight. Since there is little radiation to be absorbed by them, both will record the temperature of the air. But in sunlight the reading of the coated instrument will rapidly become higher than that of the ordinary thermometer. Can you explain why? Can you guess what would happen if the two thermometers were placed near a cake of ice? Try it.

Measuring Radiation. A simple instrument for demonstrating the presence of radiant heat is the *radiometer*, shown in Fig. 16–9. It consists of four vanes mounted on a shaft that turns freely inside a partially evacuated glass bulb. One side of each vane is coated with lampblack and the other side is shiny. When radiation falls on the black surface it is absorbed and the temperature of the surface rises. The radiation is reflected from the shiny side as from a mirror and the temperature of that side of the vanes does not rise. Air molecules in contact with the dark surface are heated and move about more briskly, thereby pushing away the black surface and making the shaft rotate.

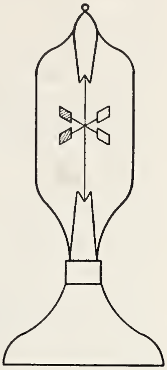


Fig. 16–9. A radiometer whose vanes whirl when radiant heat falls on them.

Land and Sea Breezes. Convection and radiation produce large-scale effects in the earth's atmosphere. One example is the breeze at the seashore. A sea breeze is a small-scale wind that often blows along the seashore and along the shores of large lakes on clear sunny days. It begins as a gentle wind a few hours after sunrise, blows strongest in the early afternoon, and dies out about sunset.

To understand what causes this breeze, let us consider the action of the sun's radiation on the land and the water. Both the land and the water absorb heat from the sun's radiation and begin to warm up as soon as the sun rises. The land, however, is a better absorber than the water; and a given amount of absorbed heat raises the temperature of land more than that of water. As a result of both these effects the land is heated faster than the water, and the air above the land becomes quite warm. This warm air expands and rises, and a convection current is started in which the cooler air from the water flows in toward the land to replace the warm air. Fig 16–10 shows the direction of this convection current, which is called a *sea breeze.*

The sea breeze does not blow far inland. On summer days the temperature may be very high a few miles inland, whereas near the shore, where the sea breeze blows, it may be ten or twenty degrees cooler.

During the night both land and water radiate heat to outer space. Since the land is a good radiator it cools off faster than the water. As a result the air over the land cools and the air over the water, being warmer than the air over the land, rises. Cold air from the land then blows out over the water to form a convection current called a *land breeze.* Notice

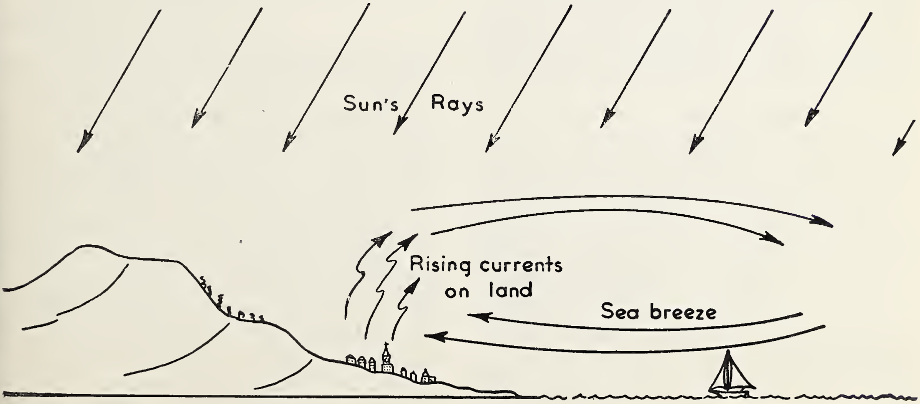


Fig. 16–10. The sun heats the earth more than the water and thereby produces a sea breeze.

that a land breeze blows in the opposite direction from a sea breeze.

AIR CONDITIONING

Insulation. For pleasant and healthful living a house should not be too cold in winter nor too hot in summer. In the past far more emphasis has been placed on heat in winter than on coolness in summer. In recent years, however, it has been discovered that the same insulating material that prevents a house from losing heat in winter will also keep it cool in summer.

Heating a house, as we have seen, requires careful planning. Conduction, convection, and radiation all play a part in the transfer of heat from the furnace to the various parts of the house. If the heating system is to be efficient, precautions must be taken to see that the heat does not leak out of the house. For this reason up-to-date houses are *insulated* with a material, such as rock wool, that is forced into the spaces between the inner and outer walls of the house and under the roof. Rock wool is a rather fluffy material made by melting certain kinds of rock and then blowing it into fibers by compressed air. ① Both the fibers and the air between them are poor conductors of heat, and ② the tangled mass of fibers prevents convection currents from forming. Insulating a house in this way results in a considerable saving of fuel and may, in a few years, pay for the cost of installation.

Insulation also keeps the house cooler in summer, since the sun's heat cannot penetrate the insulating layer. A drop in temperature of 10 degrees centigrade has been achieved by insulating a house in this way. More comfort can often be obtained by installing a fan in the attic to push the warm air out and thus draw cool air up from the lower floors. This is especially helpful at night, when the air outdoors cools more rapidly than that in the house.

Relative Humidity. Air may be too dry or too moist for comfort. Too little moisture in the air may cause the air passages of the nose and throat to dry out. Excess moisture makes doors swell and stick, and is harmful to furniture; whereas too little moisture dries out furniture and may cause it to fall apart. Modern air conditioning therefore includes the control of moisture.

The effects of moisture in air depend on both the water vapor present and the temperature. When air is warm it can hold more water vapor than when it is cold. For example, on a warm, moist summer day a glass of ice water soon becomes covered with drops of water. This is due to the fact that the warm air in contact with the cold glass is cooled so much that the moisture in the air condenses on the surface of the glass. Dew on plants and frost on windowpanes are produced in the same way.

More important than the *amount* of moisture in the air is the *relative humidity*. Warm air can hold more moisture than cold air. Relative humidity is the ratio of the actual amount of water present to the maximum amount of vapor the air can hold at that temperature. Or,

$$\text{Relative humidity} = \frac{\text{Moisture present in air}}{\text{Maximum amount possible at that temperature}}$$

Relative humidity is usually expressed as a percentage. For instance, if air contains half as much moisture as it can hold at a given temperature, the relative humidity is 50 percent. If the air contains all the moisture possible at a given temperature, the relative humidity is 100 percent, and we say that the air is *saturated*. If saturated air is cooled, moisture condenses as a fog or rain. That is why walls get wet and pipes sometimes drip in the summer. Warm moist air enters a cool house; as it cools, it becomes saturated, and some of the moisture condenses on the walls and pipes. If air is warmed, the relative humidity drops, which accounts for the frequent dryness of the air in a house in winter.

A good air-conditioning system adds water to air in winter when it becomes too dry, and removes moisture in summer. For comfort, when the temperature of the air in a room is 68° F., the relative humidity should be between 30 and 60 percent.

THINGS TO REMEMBER

Heat can be transmitted in three ways: *conduction*, *convection*, and *radiation*.

Conduction is the transfer of heat through a substance from molecule to molecule.

Metals are good conductors of heat; most *nonmetals, liquids,* and *gases* are poor conductors.

Convection is the transfer of heat by fluid currents.

Radiation is the transfer of heat through space by waves similar to light waves.

White or shiny surfaces *reflect* heat; dark surfaces *absorb* it.

Dark objects *radiate* heat more rapidly than light or shiny objects. Objects radiate heat more rapidly when they are hot than when they are cool.

Insulators reduce the transfer of heat from place to place.

Relative humidity is the ratio of the amount of moisture present in air to the maximum amount of moisture the air could hold at that temperature.

QUESTIONS

A

1. Name the three ways by which heat may be transferred from one place to another. Give an example of each method.

2. State whether the following are good or poor conductors, and good or poor convectors: air; copper; water; mercury.

3. A silver teaspoon in a cup of hot water soon becomes too hot to handle. By which method is the heat of the water carried to the handle?

4. The bottom of a test tube containing water is heated in a Bunsen flame. How does the heat get from the bottom to the top of the water?

5. What is a convection current?

6. Can convection currents occur in a solid? Explain.

7. What causes a draft in a chimney?

8. If one hand is placed above and the other hand below a suspended hot iron, which feels warmer? Why?

9. How do ocean currents affect climate?

10. What do we mean by radiant heat?

11. By what method does the sun send heat to the earth?

12. Why is a heating-system radiator so named?

13. How does insulating a house help to save fuel?

14. How is relative humidity defined?

B

15. Ice cut from ponds in winter is usually packed in sawdust for storage in summer. Why?

16. How are the three types of heat loss prevented in a thermos bottle?

17. Water is a poor conductor of heat. Describe and explain a simple way of demonstrating this fact.

18. How do the molecules of a solid body assist in the transfer of heat by conduction?

19. Describe and explain what happens when a copper gauze is lowered over a Bunsen flame.

20. On a winter day linoleum may feel cold, whereas a rug in the same room and at the same temperature may feel warm. Why?

21. In designing a hot-air heating system, would you plan to have the warm air enter a room near the floor or near the ceiling? Explain.

22. How do convection currents help to heat a house that has a hot-water heating system?

23. Describe each step in the transfer of heat from the fire of a hot-water furnace to the objects of a heated room.

24. Why does an air-cooled airplane motor have many fins on the outside of the cylinders?

25. Name two ways in which radiant heat acts like light.

26. (*a*) Draw a diagram to show that only a small portion of the heat emitted by the sun is received by the earth. (*b*) Explain how the sun heats the earth but not the space between the sun and the earth.

27. On a clear night the surface of the earth radiates heat rapidly. Leaves and grass cool considerably. Does this account for the formation of dew? Explain.

28. Will the relative humidity in a house be raised or lowered when the temperature rises from 70° F. to 75° F.?

PROJECT

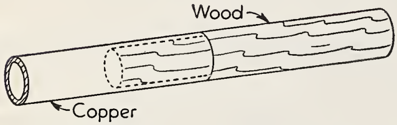


Fig. 16–11. A wooden plug in a copper pipe for demonstrating the relative heat conductivity of these materials.

To Compare the Conductivity of Wood and Copper. Obtain a piece of copper pipe 1 inch in outside diameter and 6 inches long. Trim a wooden dowel of the same size so that about one inch of it fits into the pipe as shown in Fig. 16–11. Now wrap one layer of white paper around the middle of the bar so that one part of the paper covers wood and the rest covers metal. Hold the joint in the hot air just above a Bunsen flame until the paper is scorched. Describe what happens at the joint and give a reason.

24. Explain the causes of sea breezes and land breezes

28. When the temperature in a house rises from 70° F. to 75° F. the relative humidity will be lowered ~~raised~~

Chapter 17

EVAPORATION AND BOILING

You have probably noticed that gasoline left in a shallow dish disappears in a few hours, but that water in a similar dish does not dry up for several days. The process of changing from a liquid to a gas, or vapor, is called *evaporation.* The rapid evaporation of gasoline makes it a suitable fuel in the internal-combustion engine. The steam resulting from the evaporation of water at high temperatures is used to operate steam engines. Evaporation serves other purposes. It enables us to separate crude oil into gasoline and other useful products, and it is an effective way of cooling substances.

Evaporation takes place to an enormous extent in nature. Almost 100,000 cubic miles of water are evaporated every year from the oceans of the world by the sun's heat. What happens to all this water? In the form of water vapor it is carried by winds through

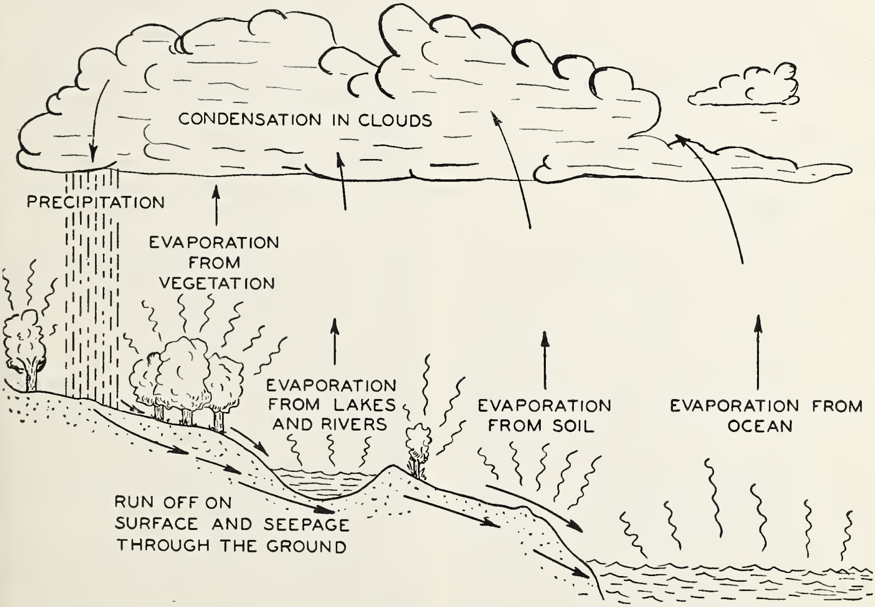

CONDENSATION IN CLOUDS
PRECIPITATION
EVAPORATION FROM VEGETATION
EVAPORATION FROM LAKES AND RIVERS
EVAPORATION FROM SOIL
EVAPORATION FROM OCEAN
RUN OFF ON SURFACE AND SEEPAGE THROUGH THE GROUND

Fig. 17–1. The water cycle.

the atmosphere and condenses into clouds. It falls to the earth as rain or snow, making the land fertile and habitable. It drains from the land, forming streams and rivers, and finally it returns to the ocean. This process of repeated evaporation and condensation in the atmosphere is called the *water cycle*. A great deal of the sun's energy is used in maintaining this cycle. The vast amount of energy required can better be realized by noting that a plant large enough to supply electricity to the city of Washington, D. C., would be able to provide only enough power to keep the water cycle in operation over a single square mile; it would take over one hundred million such plants to keep the cycle going over all the earth's surface.

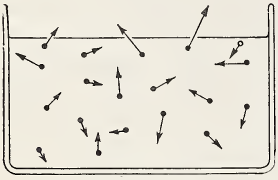


Fig. 17–2. Evaporation of a liquid. The molecules of the liquid that are moving fast enough and in the right direction near the surface escape into the air.

Cause of Evaporation. What causes a liquid to evaporate? How does evaporation cause cooling? Evaporation is really a simple process. The moving molecules in a liquid bump against each other so that some are slowed down in their motion and others are speeded up. Some of the faster-moving molecules are able to escape at the surface of the liquid. Evaporation is therefore the loss of the speediest, and hence the hottest, molecules. Since the molecules remaining in the liquid are the slower and cooler ones, *evaporation is a cooling process*. This conclusion can easily be tested by pouring a little gasoline or ether on your hand and observing that your hand feels cold as the liquid evaporates. *Note:* Ether and gasoline are both highly inflammable and must therefore not be used near an open flame.

A liquid evaporates more rapidly as its temperature is increased, for, as the liquid is heated, the molecules move faster and more of them escape. The rate of evaporation gradually increases, therefore, until the boiling point of the liquid is reached.

Boiling. You have undoubtedly often watched water boil. Do you know what causes the boiling? Let us heat some water and observe carefully what happens as the temperature rises and the water starts to boil.

Demonstration 17–1. To Boil Water.

Place over a Bunsen flame a small beaker about half full of water. With a centigrade thermometer read and record the temperature of the water every minute. Notice what happens in the water as it becomes hot and begins to boil. Continue to record the temperature until the water has been boiling for three or four minutes. What variations in temperature did you find? Describe the appearance of the water as it was being heated and as it began to boil.

As the water was heated you probably noticed many small bubbles of air forming on the sides of the beaker. These were bubbles of air that had been dissolved in the water. Why did they come out of solution? As the temperature of the water approached 100° C. much larger bubbles suddenly appeared, not only on the walls of the beaker but also in the middle of the liquid. These were bubbles of steam that expanded very rapidly. At first they collapsed before they were able to reach the surface because they were condensed by the cooler water near the surface. But when the water near the surface became hot enough, these bubbles of steam rose all the way to the top and burst there. At this point the water was boiling.

Thus the main difference between ordinary evaporation and boiling is that ordinary evaporation takes place only at the surface of a liquid, whereas, in boiling, evaporation takes place throughout the liquid.

Latent Heat. You may have also observed in the above demonstration that, once the water was boiling vigorously, the temperature stopped rising and remained at 100° C. as long as the water continued to boil. Although the water was still being heated by the Bunsen flame, there was no rise in temperature; the heat was being used to change the water from liquid to vapor. This heat is called the *latent heat of vaporization.* The heat required to change one gram of water at 100° C. to steam, or water vapor, is 540 calories; in other words, the latent heat of vaporization of water is 540 calories per gram. In terms of B.T.U. the latent heat of vaporization of water is 972 B.T.U. per pound.

A great amount of heat must be put into water in order to change it to steam. The same amount of heat is given out when the steam condenses to water. A burn caused by steam is much more severe than one caused by boiling water because a large amount of heat is released by the steam as it condenses on the skin. In fact, just as much heat is given off when steam, or water vapor, condenses as was absorbed when water was changed to steam. The absorption and liberation of latent heat are shown in Fig. 17–3.

1 gram of water from liquid to gas:
Latent heat of vaporization = 540 cal.
" " = 972 B.T.U.

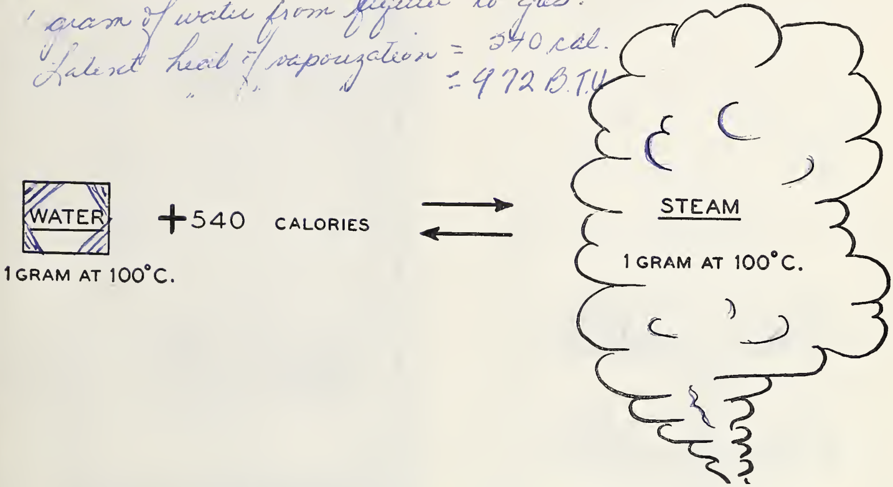


Fig. 17–3. The absorption and liberation of the latent heat of vaporization.

In our daily lives we use latent heat of vaporization and condensation for many purposes. Steam heating and cooling by evaporation are common examples. And thunderstorms, as you will learn in Chapter 19, derive most of their energy from the heat released by the condensation of water vapor.

Steam Heating. In the preceding chapter you learned that buildings can be heated by hot air or by hot water. Buildings can also be heated by steam. In fact, steam heating is the most common method of heating large buildings. In a steam-heating system water is heated to form steam, which is forced under pressure through pipes to all parts of the building. The latent heat of the steam comes from the heat of combustion of the fuel. The steam then condenses into water in the radiators. As it does so, it releases the heat supplied to it by the fuel that changed it into steam. It is this *heat of condensation,* given off in the radiators, that warms the building.

The condensed steam, or water, runs back through pipes into the boiler, where it is again changed into steam and again circulated to carry more heat to the radiators. This is shown in Fig. 17–4.

Evaporation Is a Cooling Process. If you wet the back of your hand and wave it back and forth, it feels cold; your skin is losing heat. Waving your hand increases the rate of evaporation of the water. It takes 540 calories to change one gram of water into vapor. A great deal of heat is therefore taken from your hand when the water evaporates and that is why your hand feels cold.

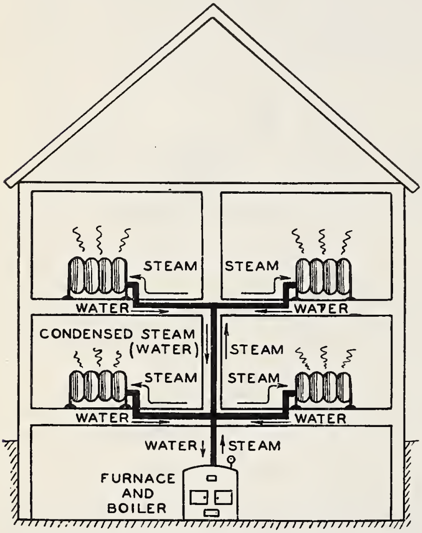
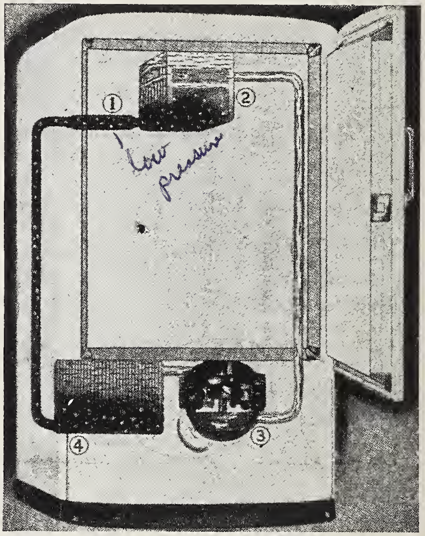


Fig. 17–4. Simple steam-heating system.

Evaporation is sometimes used in hot, dry countries to keep drinking water cool. The water is stored in large porous earthenware jugs. In such jugs evaporation occurs not only at the surface of the water but also on the outside of the jug, because the water seeps through the porous sides. The loss of heat that results from this evaporation keeps the water cool even though the surrounding air may be uncomfortably hot. The same cooling effect may be accomplished by keeping water in semi-porous canvas bags.

In a similar way the human body is cooled on a hot day because perspiration seeps through the pores of the skin and evaporates into the air. On a cold day the pores close automatically, since the body must conserve as much heat as possible in order to keep warm. Evaporation is therefore slow, and heat loss from the body is thereby greatly reduced.



Courtesy Frigidaire

Fig. 17–5. Essential parts of an electrical refrigerator: (1) evaporator; (2) freezing compartment; (3) compressor; (4) condenser. Liquid refrigerant is indicated by bubbles, vapor by wavy lines.

Refrigeration. The electric refrigerator is another device that makes use of the latent heat of vaporization. Fig. 17–5 shows the essential parts of such a refrigerator. When the interior of the refrigerator becomes too warm, a thermostat turns on the motor, which drives the *compressor*. This compresses a gas, causing it to condense to a liquid in the *condenser*, evaporation - the changing

evaporation

where the latent heat of condensation is given off to the room. The liquid then passes into the *evaporator*, where the pressure is very low. Here it evaporates rapidly, absorbing heat from the inside of the refrigerator and thereby keeping it cool. The gas then flows back to the compressor and the process is repeated.

Boiling at Low and High Pressure. When we say that water boils at 100° C., we really mean that it boils at this temperature *at sea level,* where the pressure exerted by the air on the surface of the boiling water is about 15 pounds per square inch. On the top of a mountain or high up in an airplane, where the air pressure is less than 15 pounds per square inch, water boils at a temperature below 100° C.

Courtesy Westinghouse Electric Corp.

Fig. 17–6. This refrigerator has a thermostatic control which maintains the desired temperature inside.

Demonstration 17–2. To Boil Water at Low Pressure.

Fill a round-bottom pyrex flask about half full of water and heat it until the water has been boiling vigorously for several minutes. Remove the flask from the flame, close it tightly with a rubber stopper, and place it upside down on a ring stand as shown in Fig. 17–7. Pour cold water on the flask, and notice that the water in the flask soon starts to boil again. As the water continues to boil, the flask is cooled so much that you can put your finger on it without being burned.

Latent heat of evaporation

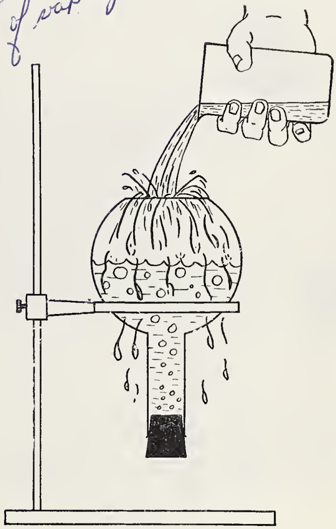


Fig. 17–7. Boiling water at reduced pressure.

The water is obviously boiling at a temperature below 100° C. What makes this possible?

When the water was boiled, the steam drove the air out of the flask so that when the flask was sealed it contained only water and water vapor. The cold water poured on the flask cooled the water vapor so much that most of it condensed, leaving the space above the water with only a little gas (water vapor) at low pressure. This reduced pressure allowed the water to boil at a temperature below 100° C. This effect applies to all liquids. We may conclude, therefore, that *if the pressure on the surface of a liquid is decreased, the liquid boils at a lower temperature.*

As we climb a mountain the pressure of the atmosphere becomes less and less, and the boiling point of water therefore becomes lower and lower. Consider what happens, for example, when food is cooked by boiling water on a high mountain, where the air pressure is relatively low. Since the water boils well below 100° C., food must be boiled much longer than at sea level before it is cooked. Cooking eggs offers still greater difficulties because the white of the egg will not coagulate (that is, become white and solid) if the temperature is below 83° C.

Courtesy National Pressure Cooker Co.

Fig. 17–8. Because of the increased pressure within the pressure cooker, the boiling point is raised and the food is cooked in less time than usual.

A Pressure Cooker. If, on the other hand, the pressure on the surface of a liquid is increased, it boils at a higher temperature. For example, if we heat water under a high pressure, it boils at a temperature higher than 100° C. and food may be cooked in a shorter time than under ordinary conditions. Fig. 17–8 shows an appliance called a *pressure cooker* that is designed for this purpose. The high pressure in a pressure cooker is obtained in a simple manner. The cover of the cooker is clamped down to make the cooker airtight, except for a safety valve which opens to let the steam escape if the pressure should become too high.

As the cooker is heated, the water inside it evaporates to form vapor. The valve is left open until the water has begun to boil, that is, until all the air has been forced out of it by the water vapor. Then the valve is closed so that the water vapor cannot escape. As more and more water vapor is formed, the pressure on the surface of the water is steadily increased. A temperature higher than 100° C. will then be required to boil the water. Finally the pressure becomes so high that steam begins to escape through the valve, a process that continues until the heat is turned off.

The steam engine is another important example of the use of high-pressure steam. In the steam engine the water boils well above 100° C., and the high pressure of the resulting steam is used to run the engine. The steam engine is described in Chapter 31.

Evaporation of Solids. Evaporation is not limited to liquids, for even solids can evaporate. For instance, mothballs placed in a closet or drawer disappear without leaving any trace. Apparently they evaporate directly into a gas without melting and forming a liquid. It is this gas that kills the larvae of moths.

Another example of a solid that evaporates is dry ice (solid carbon dioxide). If a small piece of dry ice is placed on a table, it will disappear as a gas in a few minutes without passing through the liquid state. Dry ice is made by allowing liquid carbon dioxide, contained in a tank at high pressure, to escape into the air. As the liquid expands and evaporates, the latent heat of vaporization (which it absorbs in changing to a gas) is given off, and some of the liquid freezes into a solid.

THINGS TO REMEMBER

The *rate of evaporation* of a liquid increases when its temperature is raised.

When a liquid boils, evaporation takes place throughout the entire liquid as well as from the surface.

A liquid *absorbs* heat in changing to a gas; a gas *gives off* heat in changing to a liquid.

One gram of water *absorbs* 540 calories of heat in changing from a *liquid* to a *gas,* and *gives off* the same amount in changing from a *gas* to a *liquid.*

Evaporation is a *cooling process.*

The *boiling point* of a liquid can be *raised* by *increasing* the pressure of the gas over the liquid, and it can be *lowered* by *decreasing* the pressure.

Both steam heating and mechanical refrigeration depend upon *latent heat* for their operation.

QUESTIONS

A

1. Why does a liquid evaporate more rapidly when it is heated?

2. Name a solid that evaporates directly without passing through a liquid stage.

3. When tap water is slowly heated, small bubbles appear on the walls of the container. What do these bubbles contain?

4. When water has been heated to 100° C., large bubbles form rapidly throughout the water and rise to the surface. What are these bubbles?

5. What is the principal difference between ordinary evaporation and boiling?

6. Complete each of the following statements by supplying the correct word or phrase.
  (*a*) —?— is a cooling process.
  (*b*) The boiling point of water on the top of a mountain is —?— than 100° C.

7. What is the effect of an increase in atmospheric pressure on the boiling point of water?

8. A small piece of dry ice is placed in a test tube and after a few minutes a lighted match is thrust into the tube. The flame goes out immediately. What causes the match to go out?

B

9. How many B.T.U. of heat are released when 25 pounds of steam condense into water?

10. How many B.T.U. of heat are needed to change 300 pounds of water into water vapor?

11. What is the total amount of heat needed to raise five pounds of water from room temperature (70° F.) to its boiling point and then vaporize it?

12. Would potatoes cook more rapidly or more slowly in boiling water at the bottom of a deep mine shaft than at sea level? Give reasons for your answer.

13. How is latent heat used in an electric refrigerator?

PROJECT

To Demonstrate Cooling by Evaporation. Plug up the hole in the bottom of a small flowerpot and fill the pot with water at room temperature. Place a thermometer in the water and a second thermometer in the air nearby. Compare the readings of the two thermometers one hour later. Repeat this experiment, using an ordinary pitcher instead of the flowerpot. Can you explain the difference in temperature between the water in the flowerpot and both the air and the water in the pitcher?

REVIEW QUESTIONS ON UNIT 3

A

Which of the answers to each of the following statements is correct?

1. Heat from the sun reaches the earth by: (*a*) convection; (*b*) conduction; (*c*) evaporation; (*d*) radiation.

2. Heating an iron bar: (*a*) slows downs the molecules; (*b*) makes it contract; (*c*) makes it longer.

3. The bubbles in boiling water consist of: (*a*) empty space; (*b*) water vapor; (*c*) air.

4. A cold milk bottle may crack in hot water because: (*a*) liquids expand more than solids; (*b*) the outside of the glass becomes hot sooner than the inside; (*c*) milk bottles are made of pyrex glass.

5. Complete each of the following statements by supplying the correct word or phrase.

(*a*) Everyday temperatures are usually measured in —?— degrees, while laboratory temperatures are usually measured in —?— degrees.

(*b*) Solids expand —?— than liquids when heated.

(*c*) Rising air is —?— than the surrounding air.

(*d*) Quantity of heat is measured in —?— or —?—.

6. Determine which of the following statements are true and which are false. Then correctly reword the false ones.

(*a*) Water will not change to water vapor except when it is boiling.

(*b*) Air rises when it is warmed.

(*c*) Air warms up when it is compressed.

(*d*) Heat and temperature are both measured in degrees.

(*e*) The handle of a spoon placed in a hot cup of coffee becomes hot because of convection.

(*f*) Heating a house by hot air is possible with a furnace in the basement because air becomes less dense when it is heated.

7. Match each word in the left-hand column with the word it is most clearly related to in the right-hand column.

absolute zero	32° F.
0° C.	vacuum
liquid thermometer	lowest possible temperature
radiation	latent heat
evaporation	mercury
212° F.	thermometer
98.6° F.	37° C.
Galileo	100° C.

B

8. Name the three methods by which heat may be transferred, and give an example of each.

9. A large square wooden box has a glass top; one half of the inside of the bottom is white and the other half black. Tell what happens in the box when it is placed in direct sunlight.

10. How much heat is needed to change 100 pounds of boiling water into steam?

11. How could a bimetallic strip be made into: (*a*) a thermometer; (*b*) a fire alarm?

12. A confined volume of gas is suddenly compressed. The compressed gas is then released through a small hole. Explain any changes in temperature that take place, and give a reason for the changes.

13. Explain carefully how latent heat is utilized in a steam-heating system.

14. Calculate the amount of heat needed to convert one pound of water at 72° F. into steam.

15. Draw a diagram to represent a land breeze and a sea breeze, and explain how they may be formed.

16. (*a*) A photographer should adjust the temperature of his solutions to 68° F. for best results. If he has only a centigrade thermometer, what temperature should he use on the centigrade scale?

(*b*) If his solutions are kept at 50° F. in a refrigerator, how many centigrade degrees must they warm up before he can use them? Compute this in two ways.

(*c*) How many calories will be needed to warm 2 quarts of solution from 50° F. to 68° F.? A quart weighs about 2 pounds.

17. Describe carefully the various steps by which the chemical energy of coal heats the rooms of a house with a steam-heating system.

18. Invent a system by which a bimetallic strip and a small electric motor could close a cellar window if the temperature near the window dropped too low for safety during the night. Show the device in a diagram and explain how it works.

19. Air at room temperature and normal pressure is pumped rapidly into a steel tank until the pressure is 1,500 pounds per square inch. Describe the changes in pressure, temperature, and volume of the air:

(*a*) as it is pumped into the tank,

(*b*) as the tank is allowed to stand in a room,

(*c*) as the air is allowed to escape rapidly from the tank.

SUGGESTIONS FOR FURTHER READING

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Unit 4

WEATHER

18. WINDS AND AIR MASSES
19. FRONTS AND STORMS
20. WEATHER FORECASTING
21. WHAT IS CLIMATE?

Chapter 18

WINDS AND AIR MASSES

Weather has always played a large part in man's life. From the earliest times it has affected his food supply, his safety, and his comfort. Frosts, heavy rains, and prolonged droughts damage crops and thus reduce food supplies. To improve the safety and increase the comfort of transportation, scientists are constantly trying to conquer the unfavorable elements. Ships are built sturdy enough to navigate through severe storms. Many railroad trains and buses and some automobiles are made comfortable by air conditioning. In the air airplanes are still somewhat at the mercy of the weather, although we are learning to cope with it.

Control of the weather has long been a goal of scientists. It would be a great scientific achievement. Scientists are making progress toward the solution of the weather problem. They have found several ways of removing fog in limited areas, as, for example, around airfields. They have flown into the heart of

Courtesy U.S. Air Force

Fig. 18–1. Accurate weather information is necessary before the pilot takes his plane aloft.

violent storms to learn what goes on there. By dropping pellets of dry ice into clouds they have produced rain. They know that weather is due to such factors as the unequal heating of the surface of the earth by the sun's radiation, the amount of water vapor in the air, and the rotation of the earth. But there are many other aspects of the weather that are not completely understood. Until they are known, complete control of the weather will be impossible.

Although weather cannot yet be controlled, meteorologists are able to predict with considerable accuracy the weather for the following day or two days. The prediction of bad weather, for example, gives people time to protect crops and property, and warns aircraft so that they can by-pass storm areas. Every civilized country has a weather-forecasting service. The Meteorological Division of the Department of Transport, with its headquarters in Toronto, serves this country and the world. But before discussing forecasting, let us consider some of the causes of weather.

WINDS

Most of the heat that the earth receives from the sun is absorbed, and this keeps the earth warm. Different parts of the earth absorb different amounts of heat. The equator, for example, receives more heat than the polar regions. This unequal heating causes large-scale convection currents in the atmosphere.

We might expect the air over the equator to rise vertically and flow at high altitudes directly toward the cooler regions north and south, and cold air from the North and South poles to flow over the ground directly toward the equator. If this were so, the wind in the Northern Hemisphere would blow from the north and in the Southern Hemisphere from the south, and at the equator and the poles there would be little or no wind.

Factors Affecting Winds. But the circulation of air is not so simple as that. It is complicated by three factors: (1) the rotation of the earth, (2) the distribution of large areas of land and water, and (3) the season of the year. The rotation of the earth from west to east causes the winds to veer, and blow, not from the north or south, but from the northeast or southeast. If you have tried to walk on a merry-go-round while it was in motion, you know that some force, due to the rotation of the merry-go-round, pushes you sideways. A similar force acts on the air as it moves from the poles toward the equator and deflects it from a north-south direction.

Large masses of land and water also affect the circulation of air. The land is heated faster than the water, and convection currents carry heat from the land to the water. In addition, different parts of the earth receive different amounts of heat from the sun, depending on the season of the year. The result is a circulation like that shown in Fig. 18–2.

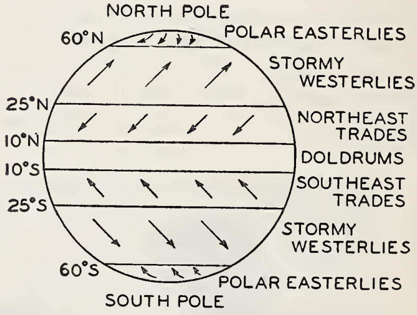


Fig. 18–2. Wind belts of the world.

Prevailing Winds. If you were to observe and record the direction of the wind at a high and exposed place several times a day for a year, you would find that in general the wind blows more often from one direction than from any other. The wind from that direction is called the *prevailing wind.* In southern Canada and in most of the United States, the winds blow generally from a westerly direction. These winds are known as the *prevailing* *westerlies*. Over corresponding latitudes in the Southern Hemisphere, the prevailing westerlies blow from the northwest.

You will notice in Fig. 18–2 that on both sides of the equator, that is, between latitudes 10° N. and 10° S., there is a region called the *doldrums*. Here there is little or no wind. In the days of sailing ships navigators tried to avoid this region. They preferred to sail between latitudes 10° N. and 25° N. or between latitudes 10° S. and 25° S. In these regions winds blow fairly steadily day and night, from the northeast in the Northern Hemisphere and from the southeast in the Southern Hemisphere. When sailing westward from Europe toward North America, navigators found it advantageous to sail a route, between 10° N. and 25° N., where the northeast winds would speed their ship westward. It was because these winds were of so much help to trading vessels that they were named *trade winds*.

Like the captains of sailing ships, pilots of airplanes take the direction of prevailing winds into account when planning long trips. More time is required to fly an airplane from Halifax to Vancouver than to fly the same plane from Vancouver to Halifax. This is due to the fact that when a plane is traveling west it flies *against* the prevailing southwest wind, but when it is flying east, the prevailing southwest wind is a tail wind that speeds it along. For this reason speed records for transatlantic and transcontinental flights have usually been made on west-to-east trips. In addition to the longer time required, a larger supply of gasoline must be carried on the east-west trip, with a resulting loss in payload.

In Fig. 18–3, notice the vertical convection currents at different latitudes. Near the equator, where the earth receives its greatest amount of heat, the heated air rises and there is little horizontal movement of air. This explains the lack of wind in the doldrums. Just north and south of the doldrums, the cooler air moves in horizontally to replace the hot air that has risen over the equator. This cool air, moving horizontally, is the trade wind. Around the North and South poles there is little wind because here cold air is descending.

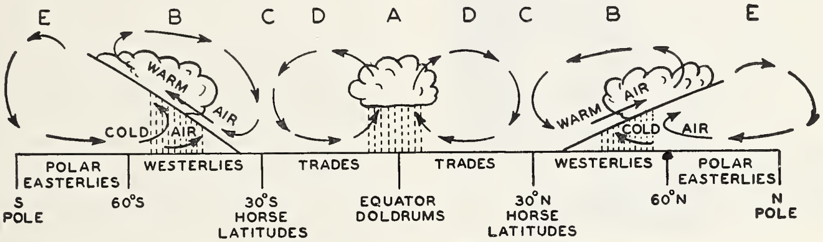
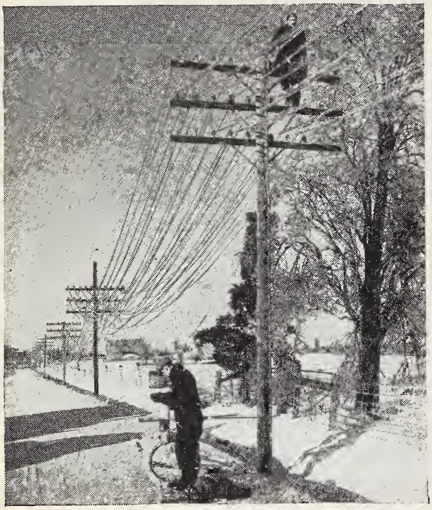


Fig. 18–3. Large scale vertical convection currents over the surface of the earth. A. *Doldrums*—Rising air, thunderstorms and rain; B. *Stormy Westerlies*—Warm-air masses from south forced to rise over cold-air masses from north giving cyclonic storms and rain; C. *Horse Latitudes*—Descending air, fair weather, little wind and few storms; D. *Trades*—Steady surface winds and fair weather; E. *Descending Air*—Clear weather and few storms.

AIR MASSES

The flow of warm air from the equator and the return of cold air from the polar regions are not steady. Instead, at irregular intervals large parcels of air, perhaps 500 to 5000 miles in diameter and several thousand feet deep, move southward from the arctic or northward from near the equator. These *air masses*, as they are called, form in the polar regions and near the equator—areas relatively free from wind. Each air mass is made up of a volume of air that has nearly the same temperature and humidity at any given altitude throughout its extent.

The cool air masses that originate in the Canadian Arctic are known as *Continental Polar Air masses*. The largest of these may cross the country at a rate of several hundred miles a day causing cooler temperatures. *Polar air* is usually dry and clear bringing crystal-clear cool days in summer. But in early winter it may cause cloud and snow after passing over a large body of water whose temperature is several degrees warmer. This is true of the Great Lakes region.



Courtesy American Telephone and Telegraph Co.

Fig. 18–4. A sleet storm often disrupts the communications system. Sleet is formed from falling rain that passes through a layer of the atmosphere below freezing temperature.

Why is a cold-air mass like the *Continental Polar* so dry? We can answer this question by following such an air mass on its journey from the Arctic Circle across Canada. In northern Canada and Alaska there is very little open ocean from which water might evaporate into the air, and in this region the surface of the earth is covered with snow and ice from which only a small amount of moisture evaporates. Therefore, when the Continental Polar air mass reaches southern Canada, it is dry.

Most of the *warm*-air masses that move over the prairies and eastern Canada come from regions near the equator in the Atlantic and Pacific oceans. These outbreaks of *tropical Gulf* or *tropical Atlantic air* have been heated near the equator and have absorbed large quantities of water vapor from the ocean. In summer this air brings hot uncomfortable weather and rain. In winter it is responsible for most of our snowfall and the occasional midwinter thaw and rain, particularly in eastern Canada.

In the prairies the annual precipitation is light, but fortunately most of it falls during the important growing season. In Manitoba rain is chiefly due to the northward movement of moist Tropical air. Farther west in Saskatchewan and Alberta rain and thunderstorms are caused by cool arctic air lifting the warm air over the prairies. When these cool waves are infrequent, there is less rainfall, and farmers suffer because their crops are below normal.

THINGS TO REMEMBER

Trade winds blow steadily from the northeast in the Northern Hemisphere and from the southeast in the Southern Hemisphere.

Trade winds are found between latitudes 10° N. and 25° N. and between latitudes 10° S. and 25° S.

The *doldrums* are a belt around the equator where there is little or no wind.

The *prevailing winds* in Canada are mostly from the west.

A *cold-air mass* is a large cold dry mass of air that originates in the arctic or antarctic regions.

A *warm-air mass* is a large warm and usually moist mass of air that originates in the semi-tropics.

QUESTIONS

A

1. Name three factors that help determine the weather over the world.
2. What and where are the trade winds?
3. What and where are the doldrums?
4. What is a prevailing wind?
5. What are air masses?

B

6. Why does it take less time to fly eastward across the country than it does to fly westward?
7. Explain why the trade winds blow from the northeast in the Northern Hemisphere.
8. Study the factors that determine the weather conditions in your locality during the various seasons of the year.

PROJECT

Determining the Direction of a Prevailing Wind. Find a tall building with a flag that is flown every day. From the direction in which the flag blows determine and record the direction of the wind twice a day for two weeks. Make your observations at the same time each day. From your records determine the prevailing wind direction during this period.

Chapter 19

FRONTS AND STORMS

Our weather changes at comparatively short intervals, and it is not the same everywhere at one time. Let us see what causes these changes. They are due to the movements of air masses. A sudden change in weather usually occurs in the area over which the boundary between a cold-air mass and a warm-air mass passes. This boundary is called a *front*.

Suppose two air masses of different temperature are moving across the land. When the warmer air is pushing the colder air before it, the moving front between the air masses is called a *warm front.* If the colder air is pushing back the warmer air, we have a *cold front.* These two types of fronts produce very different weather.

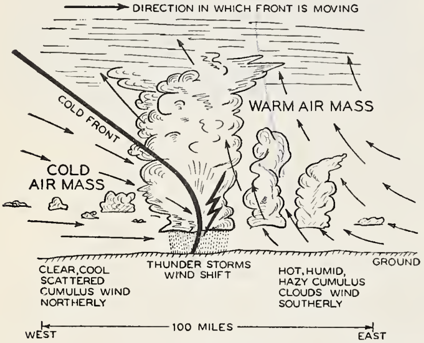
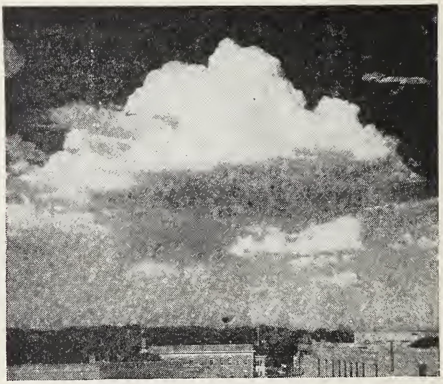

DIRECTION IN WHICH FRONT IS MOVING
COLD FRONT
WARM AIR MASS
COLD AIR MASS
GROUND
CLEAR, COOL SCATTERED CUMULUS WIND NORTHERLY
THUNDER STORMS WIND SHIFT
HOT, HUMID, HAZY CUMULUS CLOUDS WIND SOUTHERLY
100 MILES
WEST
EAST

Fig. 19–1. A vertical cross-section of a cold front.

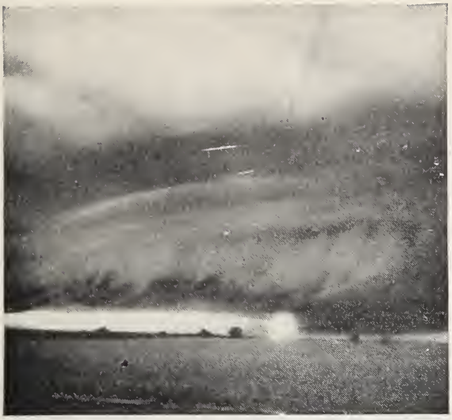
A Cold Front. Fig. 19–1 is a diagram of a cold front. At the left is the mass of cold, clear air which is moving to the right and wedging under a warm, humid air mass at the right. The warm air, being lighter, is forced up over the wedge of cold air. As it rises, it expands because of the lower atmospheric pressure at higher altitudes. In expanding, the rising air cools. As it does so, the water vapor in it begins to condense in the form of clouds called *cumulus clouds.* Cumulus clouds, as shown in Fig. 19–2, are big and fluffy and sometimes are called *woolpack* clouds because of their appearance. If the warm-air mass contains enough moisture, the cumulus clouds tower up into huge mountains of condensed vapor and develop into thunderstorms.



Courtesy H. T. Floreen from U.S. Weather Bureau

Fig. 19–2. Cumulus clouds are formed by the condensation of water vapor in rising warm air.

Let us suppose that you live at a point



Courtesy Walter Henderson from U.S. Weather Bureau

Fig. 19–3. These heavy dark clouds mark the edge of an approaching cold front.

located on the right side of Fig. 19–1. What changes in the weather do you notice as the cold front approaches and sweeps over you? To begin with, you are in the warm-air mass, and the weather around you is therefore warm and humid. The air is hazy and the wind is probably southerly. As the cold front approaches, in the west you see cumulus clouds becoming larger and thicker. Soon a solid bank of dark clouds approaches from the west. When it arrives, the southerly wind begins to shift and to blow in sharp gusts, and for a short time heavy rain falls. This indicates that the cold front is now passing directly overhead. Then the rain stops, the wind blows less violently, now from the northwest, and the clouds begin to thin out. The air that now surrounds you is that of the cold-air mass. It is cold and clear, and it probably brings relief from the hot sticky air that preceded it. The time from the approach of the cold front until the air has become clear and cool may be only half an hour or an hour.

Not all cold fronts are so noticeable as the one described. If the warm-air mass contains a slight amount of moisture, there may be no rain along the front, and the air and the wind direction may change so slowly that only a meteorologist would be aware of the passage of a front.

A Warm Front. The changes that occur in a warm front (Fig. 19–4) are much more

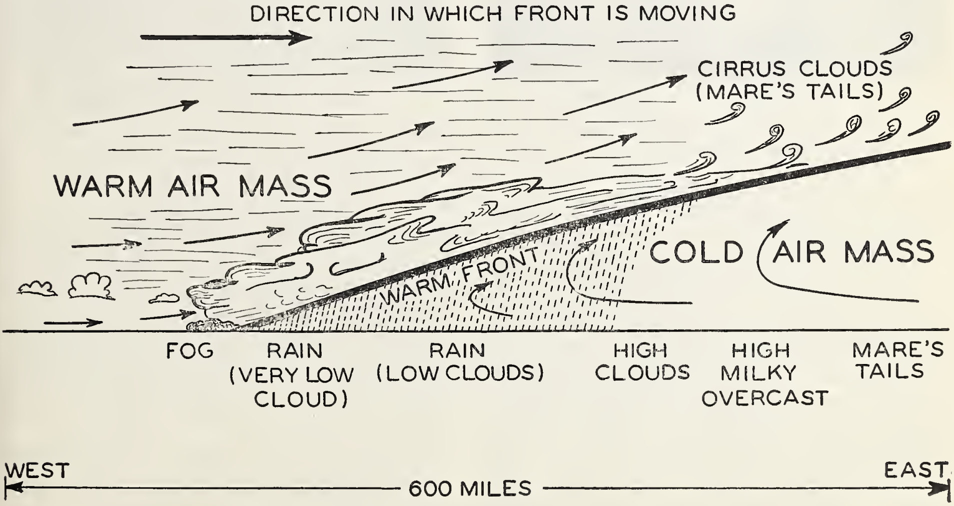
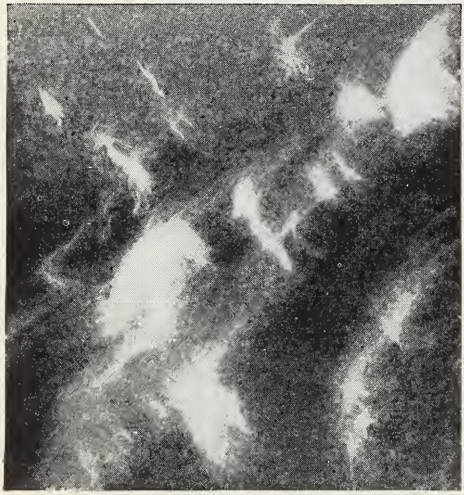


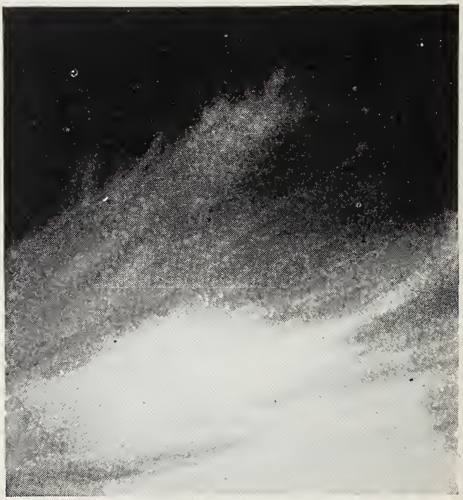
Fig. 19–4. Vertical cross-section of a warm front.

gradual and less violent than those in a cold front. The first sign of the approach of a warm front is the appearance of a form of *cirrus* clouds called *mare's-tails* at a high altitude. These thin, semi-transparent wisps of clouds are shown in Fig. 19–5. They form over a warm front at high altitudes, where the temperature is low, and are therefore composed of tiny ice crystals. Since the wind velocity at high altitudes is always greater than that near the ground, the cirrus clouds are blown far ahead of the warm front and give warning of its approach.



U.S. Weather Bureau

Fig. 19–5. Mare's tails—a form of cirrus cloud that often heralds an approaching warm front.



Courtesy A. J. Weed from U.S. Weather Bureau

Fig. 19–6. As a warm front approaches, the mare's tails fuse into a sheet of cirrus cloud.

The sky then becomes covered with a thin layer of cirrus clouds, like those shown in Fig. 19–6, which slowly become thicker and lower, until finally the sky darkens and a steady rain begins to fall. The rain increases in intensity until the front actually arrives and the warm-air mass makes its appearance. Then the rain gradually stops. The clouds thin out until only a few puffy cumulus clouds remain, and we find ourselves in the midst of a mass of warm, humid, and hazy air that is typical of a warm-air mass.

The passage of a warm front, from beginning to end, may take from one to two days, and the total amount of precipitation (rain or snow) is much greater than the brief shower that accompanies a cold front. There are two reasons why warm-front rains last so much longer than cold-front rains. ① One reason is that warm fronts generally move across the land more slowly than cold fronts. The other reason can be understood by comparing the lines marking the fronts in Fig. 19–1 and Fig. 19–4. You will notice that ② the slope of the warm front is not nearly so steep as that of the cold front. Since most rain occurs near the front, a much larger area of precipitation is covered by the warm front than by the cold front; hence a warm-front rain lasts longer and changes more gradually.

In the winter the passage of cold and warm fronts is much the same as in summer, except that we may have snow instead of rain.

counter - clockwise
inward
upward
low pressure

clockwise
outward
downward
high pressure

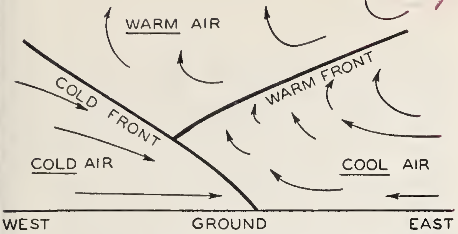


Fig. 19–7. A vertical cross-section of an occluded front. The warm front has been lifted off the ground near the center of a cyclone by the rapidly moving cold front.

If a warm-air mass overtakes a cold-air mass, and more cold air overtakes both, the warm-air mass is wedged up off the ground between the other two. This forms an *occluded front*.

Cyclones and Anticyclones. Another factor that determines weather is the atmospheric pressure. This pressure varies between high or low. Winds are caused by differences in pressure. A *cyclone*, or low, is a whirlpool of air at low pressure moving counterclockwise (in the Northern Hemisphere) toward the center and upward. An *anticyclone*, or high, is a larger whirlpool of air at high pressure moving clockwise (in the Northern Hemisphere) outward and downward. The cyclone may be several hundred miles in diameter; the anticyclone is frequently much larger.

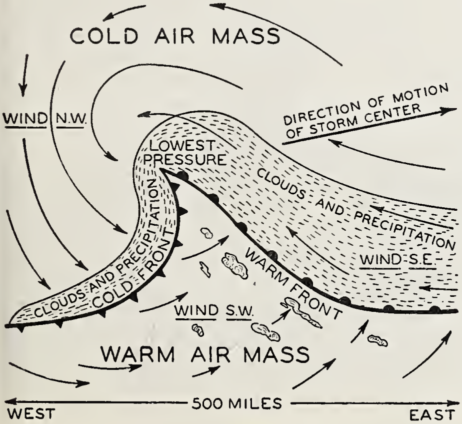


Fig. 19–8. A Cyclonic storm as it appears on a weather map.

Anticyclones generally bring fair weather. Cyclones, however, frequently bring stormy weather. As these lows move in, and the barometer, which measures atmospheric pressure, drops, bad weather can be expected. A cyclone should not be confused with a tornado or hurricane, which are discussed on page 171. Although bad weather, including severe storms, may occur with a cyclone, many cyclones pass by with no more than high winds and occasional showers.

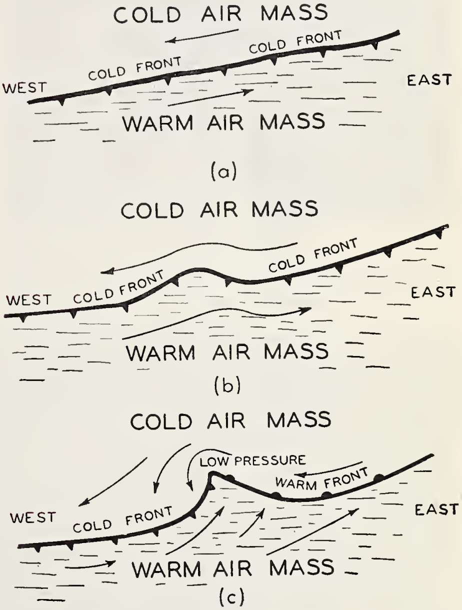
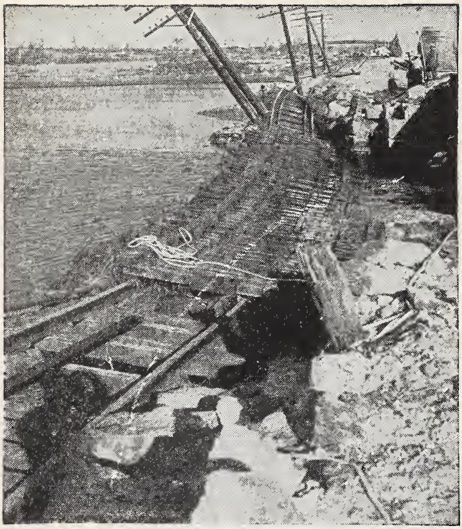


Fig. 19–9. The development of a cyclone.

Cyclones originate along a front. Fig. 19–9 shows how such a front may develop a slight bulge, accompanied by a drop in atmospheric pressure. As this bulge grows larger, warm air moves into it and the cold air moves in a curve around it, as shown in (*c*). As the pressure becomes lower and the winds become stronger, a cyclone develops. The development of a cyclone takes from one to three days, and it may last for several days, moving from west to east across the country. Eventually the cold front overtakes the warm front, giving rise to an occluded front. The cyclone dies out soon after the occluded front forms.

What changes in weather might we expect as a cyclone approaches and moves over us? Assume that the cyclone is moving eastward and that its center passes just to the north of us. First we would observe the wind direction to be south. The barometer would fall, the wind would rise, and it would begin to rain. Then, after the warm front had passed over us, we would have warm unsettled and partially clear weather for perhaps a day. Then, after a brief but heavy shower, the barometer would begin to rise, the wind would blow



Courtesy New York, New Haven and Hartford Railroad Co. from U.S. Weather Bureau

Fig. 19–10. Damage to a railroad in New England by hurricane, September 22, 1938.

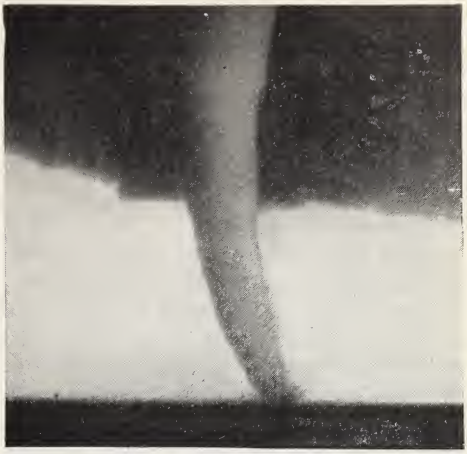
U.S. Weather Bureau

Fig. 19–11. Coast Guard ship, flying the warning signals of a storm of marked violence with winds beginning from the northeast, passes close to a small craft that has no other way of knowing of the impending storm.

from the northwest, and the weather would clear.

Hurricanes. *Hurricanes* are similar to cyclones, but, unlike cyclones, they always originate over water near the equator and never over land, and they are not formed along fronts. Scientists are not quite sure what causes them, but they are probably the result of strong heating of the ocean near the equator that results in a spiraling updraft covering an area of hundreds of square miles. The winds of a hurricane are much more violent than those of a cyclone, and they cause destruction running into millions of dollars every year.

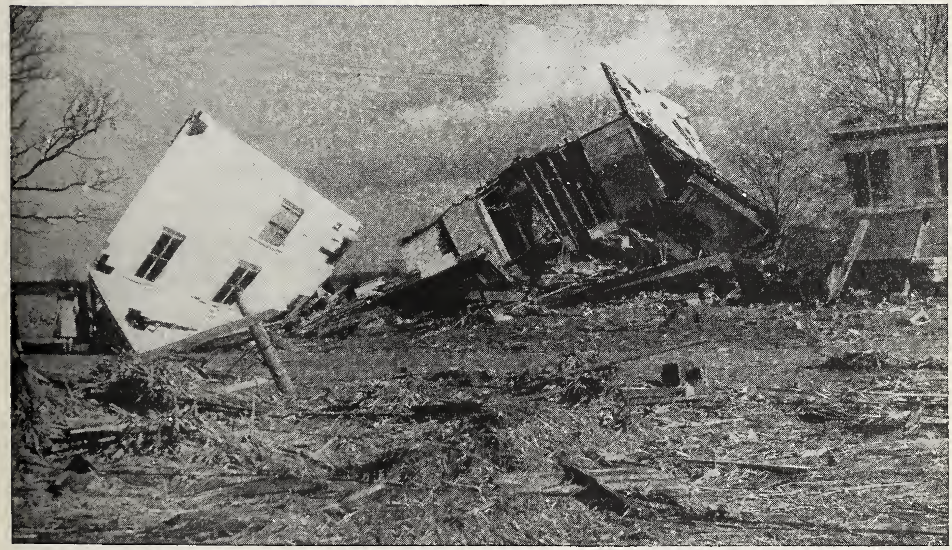
Hurricanes occur most frequently along the southeastern coast of the United States. They rarely reach far inland because the friction offered by rough and tree-covered land is so great that it rapidly reduces the wind velocity and the storm thus wears itself out. Moreover, hurricanes gain their energy from the latent heat of condensation of evaporated sea water. As the hurricane moves over the land this supply of energy is cut off.



Courtesy Ira B. Blackstock from U.S. Weather Bureau

Fig. 19–12. The whirling funnel-like cloud of a tornado in Kansas.

The hurricane that struck New England in



Courtesy Detroit News from U.S. Weather Bureau

Fig. 19–13. Tornado destruction at Howell, Michigan, April, 1941.

1938 probably did greater damage than any other storm on record. It was not the most violent storm that ever occurred but it struck a part of the country that is highly industrialized and thickly populated. Since hurricanes seldom travel so far north, this region was almost completely unprepared for it.

Tornadoes. *Tornadoes* are small local cyclones that start on very hot days and are generally accompanied by thunderstorms. They are sometimes only a few hundred yards in diameter, and they usually travel only a few miles. But they destroy nearly everything in their path. In the wind, which may have a velocity of over 200 miles an hour, houses are smashed, steel girders twisted, and freight cars blown from their tracks. Small ponds have even had all the water sucked out of them by the violent winds of a tornado. In such a case the fish, frogs, and debris from the pond are also sucked up. They fall to the ground some distance away, so that it literally rains fish and frogs. A tornado formed out at sea is called a waterspout.

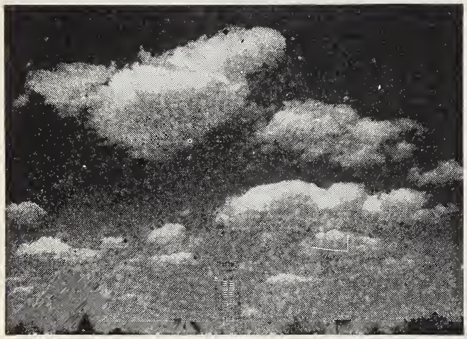

Courtesy H. T. Floreen from U.S. Weather Bureau

Fig. 19–14. Typical fair-weather cumulus clouds.

Thunderstorms. Hot summer days often give rise to thunderstorms. On such days the air just above the hot ground becomes warm, expands, and starts to rise, forming a fountain of warm air that may rise more than a mile in the atmosphere. At the same time cool air rushes in along the ground to take the place of the rising air and causes strong, gusty squalls of wind. As the air rises, it expands because of the lower pressure at higher altitudes, and therefore becomes cooler. The air cools to saturation, condensation begins, and cumulus clouds are formed. Sometimes they look like those in Fig. 19–14, which are called *fair-weather cumulus* because they appear on warm sunny days. If there is much moisture in the rising air, a great deal of latent heat is released when condensation takes place. This

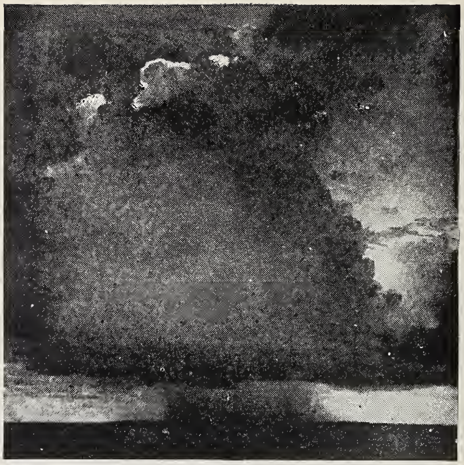

U.S. Weather Bureau

Fig. 19–15. Cumulus cloud of a thunderstorm due east of Pensacola, Florida.

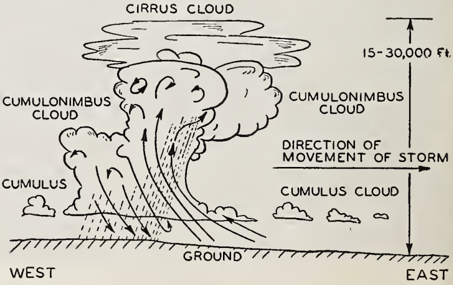


Fig. 19–16. Vertical cross-section of a thunderstorm.

heats the air, making it still lighter, so that it rises still higher and forms large towering *cumulonimbus clouds* like those in Fig. 19–15. These produce heavy, though usually brief, showers of rain accompanied by thunder and lightning. Such a towering mountain of condensed water vapor is the heart of a thunderstorm.

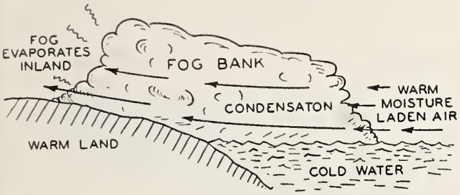
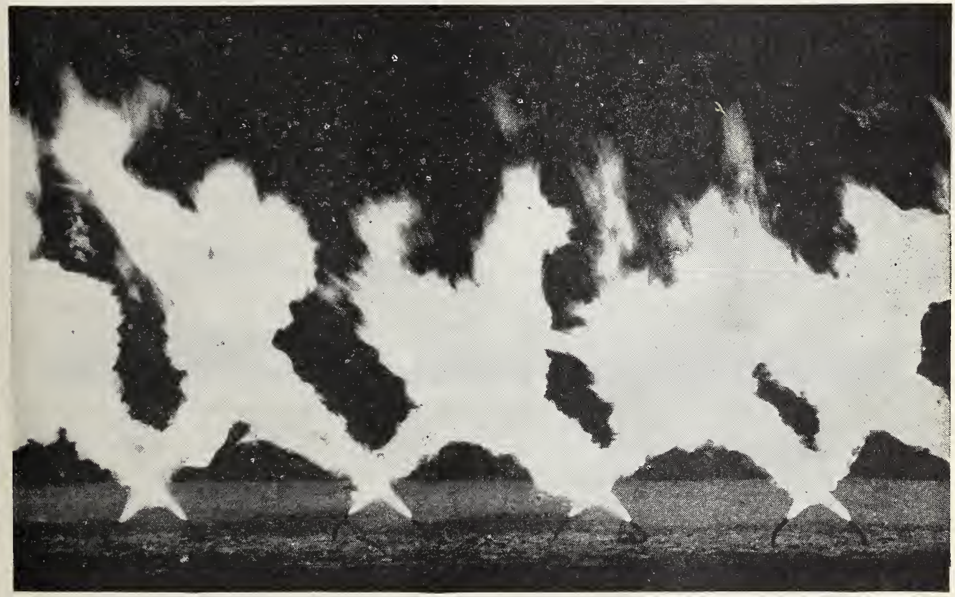


Fig. 19–17. How a coastal fog bank forms.

Whenever possible airplane pilots try to avoid cumulonimbus clouds by flying around them, for the strong updrafts and downdrafts of air within these clouds may lift a plane suddenly upward and then drop it downward, sometimes with enough force to tear off a wing.

Hail. Every year hailstorms are responsible for many thousands of dollars' worth of damage to crops. Hailstones are formed in severe thunderstorms. Small raindrops are borne aloft by a violent updraft until they reach a point in the atmosphere above the freezing level. Here they freeze and fall below the freezing level, where moisture condenses on them. They are again lifted violently upward and reach the freezing level before the inside core has had a chance to melt. The added moisture on the surface is now frozen; the hailstone falls, gathers more moisture, rises, and another shell of ice is added. Each hailstone may repeat this process many times in the violent updrafts and downdrafts of a vigorous thunderstorm, adding layer upon layer of ice until it is so large and heavy that it falls to the ground.



Courtesy U.S. Air Force

Fig. 19–18. Fog dispersal is accomplished by flames of high-pressure material developed by the Army. The Armed Forces refer to this as FIDO (Fog Intensive, Dispersal Of).

If a hailstone is cut in half, its layers of ice resemble the cross-section of an onion. The number of times it crossed the freezing level during its growth high above the earth can be determined by counting the number of its layers of ice. Hailstones vary in size. Some are no larger than a small pea, but occasionally hailstones larger than hens' eggs fall from thunderstorms.

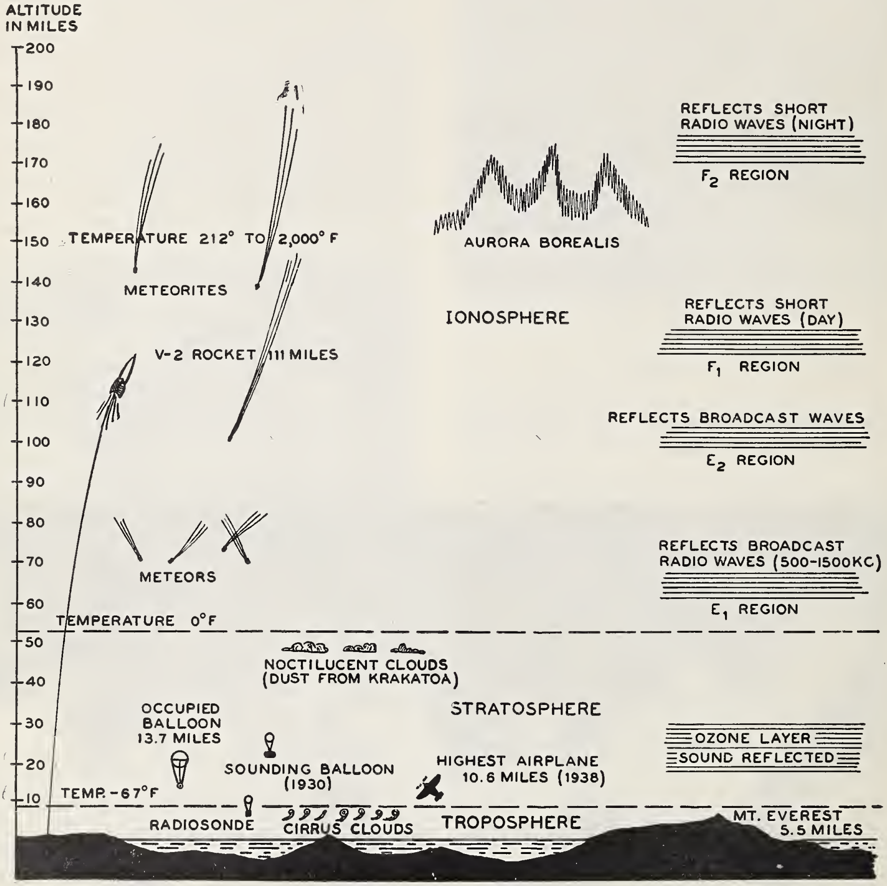


Fig. 19–19. A vertical cross-section of the earth's atmosphere.

Fog. A fog is similar to a cloud, except that it is formed on the ground rather than a thousand or more feet up in the air. It is formed when warm moist air that is nearly saturated with water vapor is cooled by contact with a cold land or water surface. When warm moist air from the Gulf Stream crosses the cold waters of the Labrador Current off Newfoundland, the Grand Banks are usually enveloped in fog. In fact, Cape Race is fogbound for as much as 158 days a year. Similar fogs occur along the coast of British Columbia. In London, where condensation takes place easily because of the large amount of soft-coal soot in the air, the fog sometimes becomes so dense that street lights must be turned on in the middle of the day.

Fogs make transportation by ship and by aircraft extremely dangerous. Millions of dollars are therefore spent each year on safety devices and weather forecasting in an effort to prevent possible accidents in thick fogs.

Monday

Dew and Frost. Water vapor that condenses on the ground at night above the freezing point forms *dew*. If the temperature of the ground is below the freezing point, the water vapor condenses to *frost*. To understand the formation of frost and dew, let us consider what happens to the ground at night. After the sun sets, the ground begins to radiate heat through the atmosphere to outer space. As the ground cools, the air close to it also becomes cooler. When the air is cooled to a certain point, the moisture in it condenses on the ground. Two other conditions are essential for the formation of dew: ① there must be no wind, and the ② sky must be clear. Even a light breeze mixes the air near the ground with the warmer air above and thus prevents condensation. If the sky is not clear, much of the heat radiated by the earth is reflected by the clouds and the ground therefore does not cool sufficiently to permit the moisture in the air to condense.

The Troposphere and the Stratosphere. All winds, storms, and changing weather take place in a thin shell of air surrounding the earth. This layer of the atmosphere is called the *troposphere*. Beyond the troposphere the temperature does not fall as we rise higher; there are no convection currents, no clouds, and little water vapor. In short, there is no weather. This outer layer of the atmosphere is called the *stratosphere*. It begins at an altitude of about 40,000 feet, where the temperature is about −67° F. It is an ideal altitude for the navigation of aircraft since it is above all bad weather. More and more planes are being constructed to fly in the stratosphere. Such planes must have pressurized cabins to provide adequate air pressure for the comfort of the passengers and superchargers to supply sufficient oxygen to operate the engines.

THINGS TO REMEMBER

A *front* is the boundary between two air masses. Rain often occurs along fronts.

In a *warm front* the warm air pushes back the cold-air mass. In a *cold front* the cold air pushes back the warm-air mass.

A *cyclone* is a low-pressure whirlpool of air moving counterclockwise, inward and upward.

An *anticyclone* is high-pressure whirlpool of air moving clockwise, outward and downward.

Cirrus clouds are high, thin clouds consisting of ice crystals.

Cumulus clouds are large puffy clouds caused by vertical convection.

Thunderstorms are the result of strong vertical convection currents that form *cumulonimbus* clouds.

QUESTIONS

A

1. Describe the formation of cumulus clouds.
2. How may rain be produced?
3. What is a cyclone?
4. What is an anticyclone?
5. What is the stratosphere?
6. How is fog produced?
7. What is the cause of dew?
8. When the barometer falls, what kind of weather is likely to follow? What kind of weather is likely when it rises?
9. Determine which of the following statements are true and which are false. Then correctly reword the false ones.
   - (*a*) Dew is most likely to form on a cloudy night.
   - (*b*) Frost is not likely to form if a strong wind is blowing at night.

(*c*) The atmospheric pressure in the center of a cyclone is high.

(*d*) A cold-air mass pushes back a warm-air mass to form a cold front.

(*e*) Thunderstorms never result from cumulonimbus clouds.

B

10. What are the principal differences between a cyclone, a hurricane, and a tornado?

11. Describe cumulus clouds and cirrus clouds.

12. Explain how a thunderstorm is formed.

13. Describe the life of a cyclone from its origin to its end.

14. What happens as a cold front approaches and passes over you?

15. What happens as a warm front approaches and passes over you?

PROJECTS

1. *Recognizing Different Types of Clouds.* Examine the sky on two or three successive days and name the cloud formations. Are there any cumulus clouds? How were they formed? Do they remain in the same place for more than an hour? What finally happens to them? Try to answer the same questions for cirrus clouds.

2. *Locating the Center of a Cyclone.* There is a useful and simple way (called *Buys Ballots Law*) to locate the center of a cyclonic storm in the Northern Hemisphere. Stand with your back to the wind and raise your *left* arm so that it is horizontal and in line with your shoulders; now move your arm so that it points slightly forward and it will point in the direction of the center of low pressure. The reason for this is that the winds in a cyclone spiral inward, counterclockwise, toward the center of low pressure.

   The next time the barometer falls and a storm approaches, try this method of locating its center. Do this every few hours for a whole day and you should be able to roughly plot the path of the low. If there is a weather map in your newspaper, you can use it to check the accuracy of your results.

Chapter 20

WEATHER FORECASTING

In Chapters 18 and 19 we discussed the causes of rain, fog, winds, and storms, and how these all go together to make up our daily weather. Knowing something about them makes the daily changes in weather fascinating to watch. To be able to say, for example, "Here comes a cold front," and then to predict and watch all the familiar changes that occur as the front passes, can increase your interest in the changing aspects of weather. In this chapter we will see how man's knowledge of the elements enables him to forecast weather.

Predicting the Weather. In order to forecast the weather for a given area a meteorologist must have exact knowledge of the present weather surrounding the area. Since air masses and fronts often move several hundred miles a day, he must know the position of all fronts and of highs and lows, and how fast they are moving. He must know the kind of clouds present and the extent of cloudiness. He must also know the direction and velocity of the winds, the amount and location of any precipitation, the amount of moisture in the air, and the barometric pressure at as many points as possible. With these data he can predict with reasonable accuracy what changes in the weather will occur in the immediate future in a particular area.

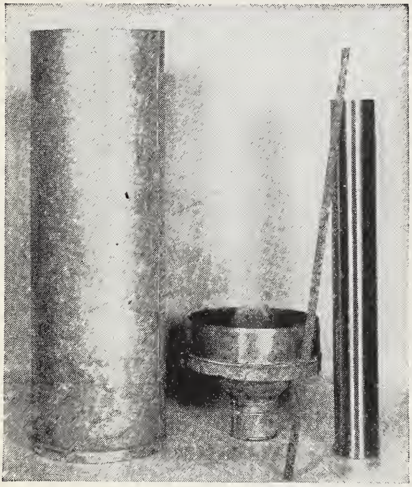
It would be impossible, of course, for one man to gather all this information in time to make a prediction that would be of any use. It takes hundreds of trained observers, scattered all over Canada and the United States, to provide a meteorologist with all the data he needs to forecast the weather. Canada's Weather Service was established and developed principally to supply this need.

The first service in the world for gathering weather data was established in Europe during the last century. At that time the telegraph had not been invented. Warnings of approaching storms were relayed by signal flags from hill to hill across the countryside. The telegraph makes possible more accurate weather forecasting. Today the meteorologist receives his information from a weather map made up every few hours from reports that are teletyped to his office by hundreds of observers in all parts of the country.

All over the country, from Newfoundland to British Columbia, official observers read their weather instruments at the same time. In Labrador it may be a cold evening as the observer throws on an overcoat and trudges out to measure the amount of snowfall. On Vancouver Island at exactly the same time, an observer may be going out in his shirt sleeves on a bright sunny afternoon to read his instruments. Pressure, humidity, wind, temperature, and so on, are all measured at the same time in each place. Some of the instruments used at every weather station are explained below.

Precipitation. Rainfall and snowfall can be measured by a rain gage such as that shown in

Fig. 20–1. The gage is placed upright in an open level place. It consists of a narrow tube in which the rain is collected through a large funnel. Tube and funnel are supported in a large outer can. To measure the rainfall, a measuring stick is inserted in the tube and then removed; the depth to which the stick has become wet is read. The cross-section area of the top of the funnel is exactly ten times that of the cross-section of the collecting tube. The depth of the water collected in the tube is therefore ten times that of the actual rainfall. With this gage rainfall can be measured accurately to one-hundredth of an inch.



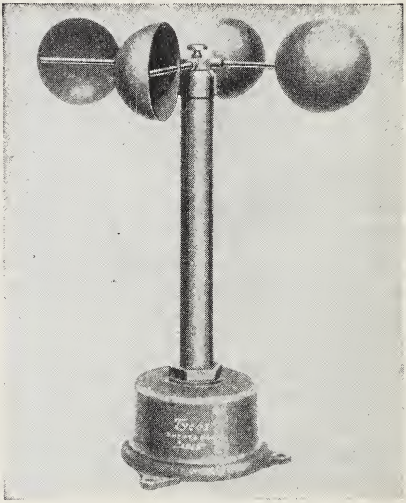
U.S. Weather Bureau

Fig. 20–1. Parts of an 8-inch rain and snow gage with measuring stick.

In winter the funnel and tube are removed. The snow collected in the large can is melted and poured into the small tube. The amount of snowfall, in terms of water content, is then read in the usual way. Ten inches of snow is approximately equal to one inch of rain.

Wind Direction and Velocity. Wind direction is indicated by a simple *weather vane*. The actual direction is usually shown by electrical means on a compass dial located in the office, where it can be conveniently read.

Wind velocity is measured by an *anemometer*, one type of which is shown in Fig. 20–2. The three cups rotate in the wind like a horizontal windmill, the speed of rotation increasing as the velocity of the wind increases. The speed of the shaft's rotation is recorded on a meter dial that indicates the wind velocity in miles per hour.



Courtesy Taylor Instrument Co.

Fig. 20–2. A Robinson cup anemometer for measuring the velocity of the wind.

Anemometers are standard equipment at every weather station, but wind velocity can be estimated when an anemometer is not available. A sea captain named Beaufort devised a set of rules, now known as the Beaufort Scale, for estimating the wind velocity at sea by the type and size of the waves. This scale has been adapted for use on land and is shown on page 179.

Barometric Pressure. The pressure of the atmosphere, or *barometric pressure*, is measured most accurately by means of a mercury

BEAUFORT SCALE OF WIND VELOCITIES

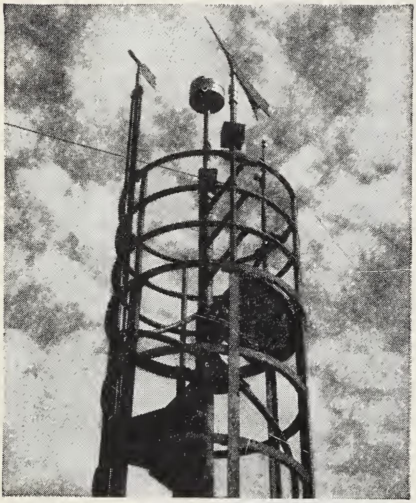
Beaufort Number	Type of Wind	Description	Velocity in mph
0.	Calm	Smoke rises vertically.	Less than 1
1.	Light Breeze	Direction of wind shown by smoke drift but not by wind vanes.	1–3
2.	Slight Breeze	Wind felt on face; leaves rustle; ordinary vane moved by wind.	4–7
3.	Gentle Breeze	Leaves and small twigs in constant motion; wind extends light flag.	8–12
4.	Moderate Breeze	Raises dust and loose paper; small branches are moved.	13–18
5.	Fresh Breeze	Small trees in leaf begin to sway; crested wavelets form on inland waters.	19–24
6.	Strong Breeze	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.	25–31
7.	High Wind (Mod. Gale)	Whole trees in motion; inconvenience felt in walking against wind.	32–38
8.	Gale (Fresh Gale)	Breaks twigs off trees; generally impedes progress.	39–46
9.	Strong Gale	Slight structural damage occurs (slates removed from roof).	47–54
10.	Whole Gale	Trees uprooted; considerable structural damage occurs.	55–63
11.	Storm	Rarely experienced; accompanied by widespread damage.	64–75
12.	Hurricane		Above 75

barometer, described in Chapter 5. A mercury barometer is found in every weather station. But another type, called an *aneroid barometer* (see Fig. 20–4A), is often used because it is more convenient than the mercury one. It consists of a small disk-like metal box from which part of the air has been removed. If the atmospheric pressure increases, the top of the small box is depressed; if the atmospheric pressure drops, the top of the box rises. The movement is transmitted to a needle on the dial of the instrument.

Relative Humidity. The water vapor in the air is measured by an instrument called a *wet- and dry-bulb thermometer*, which consists of two ordinary mercury thermometers. One thermometer is exposed directly to the air; the other has its bulb covered with a sleeve of muslin which dips into a glass of water. The apparatus is set up outdoors in a shelter that shields the thermometers from the sun's radiation but permits the outside air to circulate freely so that it may cool and heat the thermometer bulbs by conduction, thus giving an accurate reading of the air temperature.

If the air is *saturated*—that is, if it contains the greatest amount of water vapor it can hold at a given temperature—no evaporation will take place from the wet muslin. Then both thermometers will read the same. If the air is very dry, however, evaporation from the muslin will be rapid. Since evaporation is a cooling process, the wet-bulb thermometer will read lower than the dry-bulb. From the difference between the two thermometer readings the *relative humidity* can be calculated.

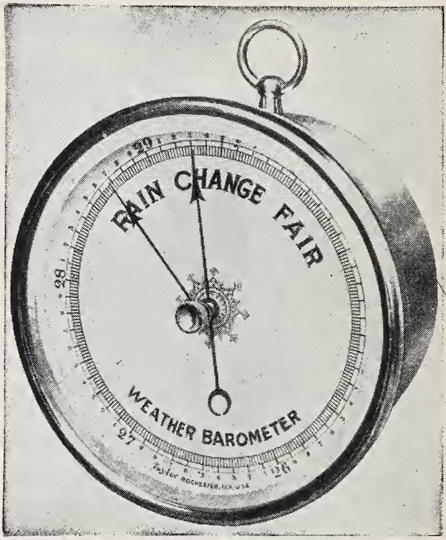
Relative humidity strongly affects human comfort. When the relative humidity is high, evaporation proceeds so slowly that the human body loses little heat by the evaporation of perspiration. Hence on a hot day when the relative humidity is close to 100 percent (a muggy day), we feel much hotter than on a hot *dry* day; our clothing becomes damp and sticky from perspiration that does not evaporate.



Courtesy L. E. Johnson from U.S. Weather Bureau

Fig. 20–3. Wind instruments. From left to right: Dines pressure tube anemometer, thunderstorm indicator, 4-foot wind vane, and 3-cup Robinson anemometer (note that this is whirling so rapidly that the cups appear only as a blur.)

Dewpoint. *The dewpoint is the temperature to which the air must be cooled in order to produce condensation.* Condensation begins to take place when the relative humidity approaches 100 percent. A knowledge of the dewpoint is important in forecasting fog. For example, suppose a flyer takes off in the late afternoon on a clear day for an airport several hours' flight away, where the temperature at the time he starts is 80° F. and the dewpoint is 76° F. He should know from these figures that there is likely to be fog over the field when he arrives, for, as evening approaches, the air will cool off. At 76° F. the water vapor in the air will begin to condense and form fog droplets, and the visibility may be reduced to the point where the flyer will find it difficult to land safely.



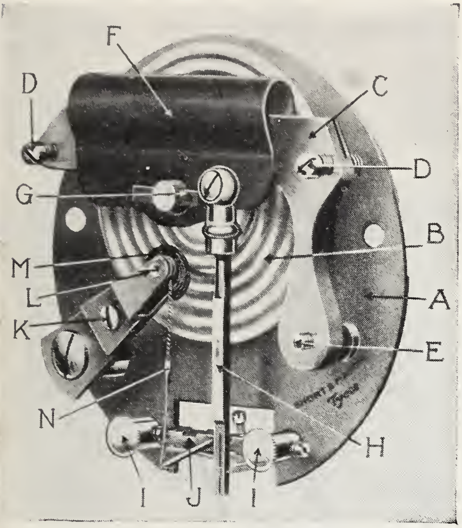
Courtesy Taylor Instrument Co.

Fig. 20–4A. The exterior of an aneroid barometer. The dials indicate atmospheric pressure in inches and millimeters.

There are instruments for determining the dewpoint directly, but it is usually obtained from the readings of wet-and-dry-bulb thermometers.

The Weather Map. Fig. 20–6 is a weather map on which is shown the information collected by observers all over the country at 7:30 P.M. Eastern Standard Time. This kind of map is published daily in newspapers throughout the country. It is a simplified map and does not contain as much information as the official weather maps used by meteorologists, but it shows the most important features of the weather throughout the country.

First, notice that the map is covered with solid black lines. These lines are called *isobars*. They indicate equal barometric pressure; all places on the same isobar have the same pressure. At one end of the line the pressure is given in inches of mercury, and at the other end it is given in *millibars*. The millibar is the unit of pressure commonly used by meteorologists; it is equal to .0295 inches of mercury; 1000 millibars are equal to 29.5 inches of mercury, which is approximately normal atmospheric pressure. For example, look at the isobar that passes through St. John's. It runs off the map just southeast of St. John's, and the figure 29.89 at this end of the line means that the barometric pressure at every point along this line is 29.89 inches of mercury. At the other end of the line we find the number 1012, which is the pressure in millibars corresponding to 29.89 inches. Isobars make it easy to locate the highs and lows across the country. They also indicate the direction of flow of the air, for the winds usually blow almost directly along the isobars, counterclockwise about a low and slightly inward toward the center, and clockwise about a high and slightly outward. The isobars also give some indication of wind velocities. If the isobars are close together, wind velocities are usually high; if they are far apart, wind velocities are low.



Courtesy Taylor Instrument Co.

Fig. 20–4B. The mechanism of an aneroid barometer; A, base plate; B, partially evacuated metal disk-like box; C, support for spring; F, spring to support top of box and keep it from collapsing under normal air pressure; H, arm that moves up and down as changing air pressure on box moves top in and out; J, lever system to magnify motion of top of box; N, flexible chain which turns the pivot, L, to which indicator hand is attached; M, hairspring to take up slack in chain when air pressure drops.

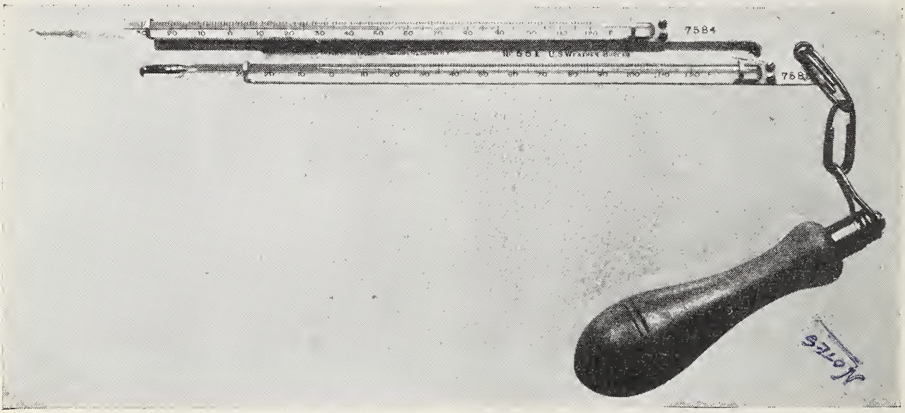
Temperature, Clouds, Wind, and Precipitation. You will notice that each city where observations of temperature, precipitation, and other weather conditions are made, is represented by a small circle. When the weather at a given station is clear, the circle is unshaded; when it is partly cloudy, the circle is half shaded; and when the sky is completely cloudy, the circle is completely shaded. Rain, snow, and fog are shown by the letters *R*, *S*, or *F* beside the circle. Beside each circle is a number giving the temperature. Where precipitation has occurred, the amount of rain in inches during the last twenty-four hours is given by a second number below that representing temperature. Notice that to each circle representing a station is attached an arrow with a number of barbs on the tail. The arrows show the direction of the wind; the barbs indicate the wind velocity on the Beaufort Scale. No arrow would mean no wind; an arrow with half a barb, a wind of 1 on the Beaufort Scale; an arrow with a whole barb, 2 on the scale; one and a half barbs, 3; and so on. Relative humidity is not given on this simplified map.

Let us examine the Winnipeg station circle.

Here we see a black circle, which means cloudy but no rain or snow. The temperature is 32° F., and the precipitation is .10, which means that there has been one-tenth of an inch of precipitation—probably snow—in the last twenty-four hours. The wind direction is northwest, and, since there are three whole barbs on the arrow, the wind velocity is between 25 and 31 miles per hour. The barometric pressure is about 1023 millibars.

Fronts and Air Masses. Fronts are shown on the map by long lines with markings along them. Along a cold front the markings are pointed. The markings are along that side of the front line toward which the front is moving. The front stretching from Philadelphia southeastwards into the Atlantic is a cold front. You will notice on the long front stretching from the Yukon Territories southward to Mexico that the warm front and cold front markings appear on opposite sides of the line. This indicates a front that is not moving; it is called a *stationary front.*

The large air mass covering the prairie provinces and the central and eastern states is a cold-air mass that has pushed down from the Canadian Arctic. One or two days before this map was made it was northwest of its present location. It has become somewhat warmer as it moved southeastward, but it is still cold enough to bring freezing temperatures as far south as the Great Lakes. In Churchill on Hudson Bay the temperature is only three degrees above zero. The area of highest barometric pressure in this air mass is centered to the east of McMurray. It is called an anticyclone You can see by the wind arrows on the station circles in this anticyclone region that, with a few exceptions due to local conditions, the air is spiraling outward in a clockwise direction from the center of high pressure. The temperatures in the western half of this air mass are generally higher than those due east in the other half. The reason for this is that the air in the western half comes from the south where it has been warmed, while the air in the eastern half comes from colder regions to the north.



U.S. Weather Bureau

Fig. 20-5. A form of wet- and dry-bulb thermometer called a *sling psychrometer,* which is whirled about in the air to facilitate evaporation from the wet muslin on the wet-bulb thermometer.

Suppose we take an imaginary flight from Calgary, in the cold-air mass, where the temperature is 59 and the wind is east-southeast, 1 millibar = .0295

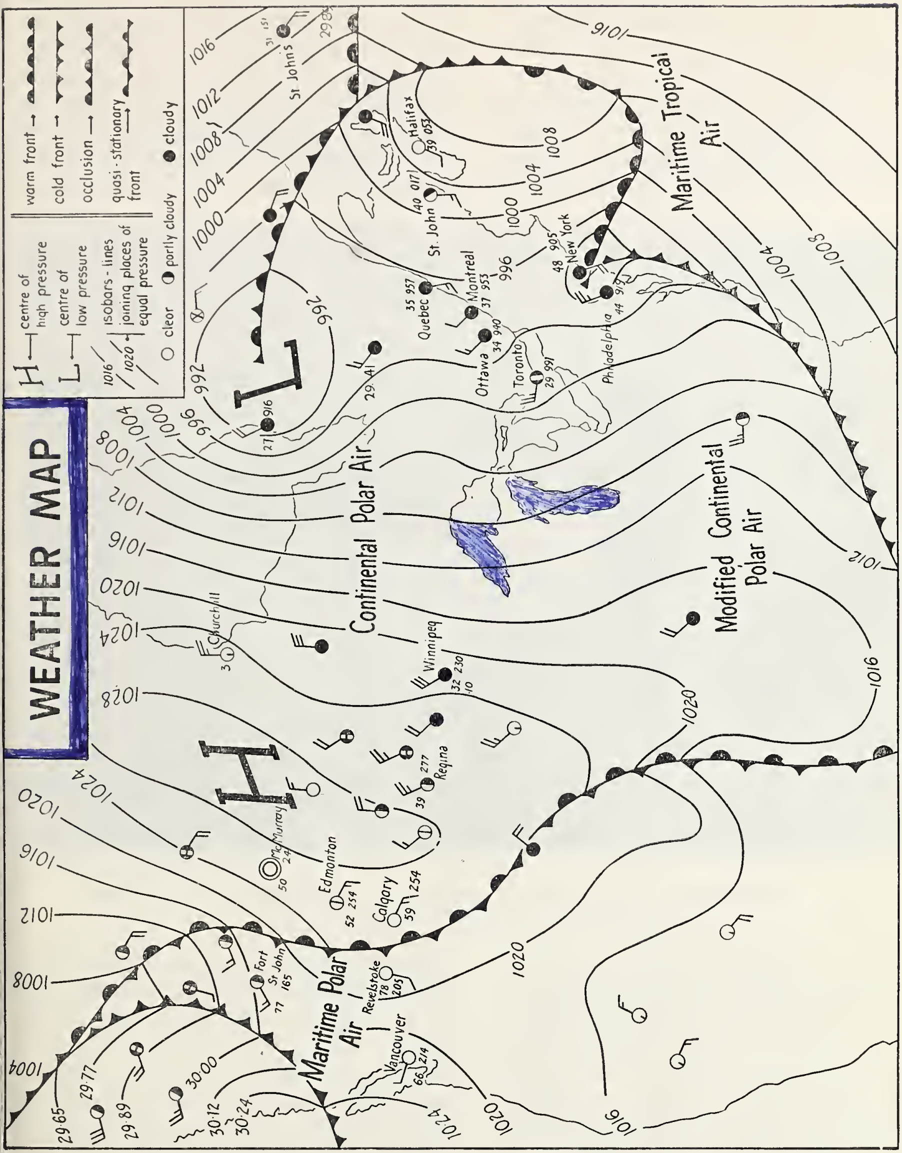
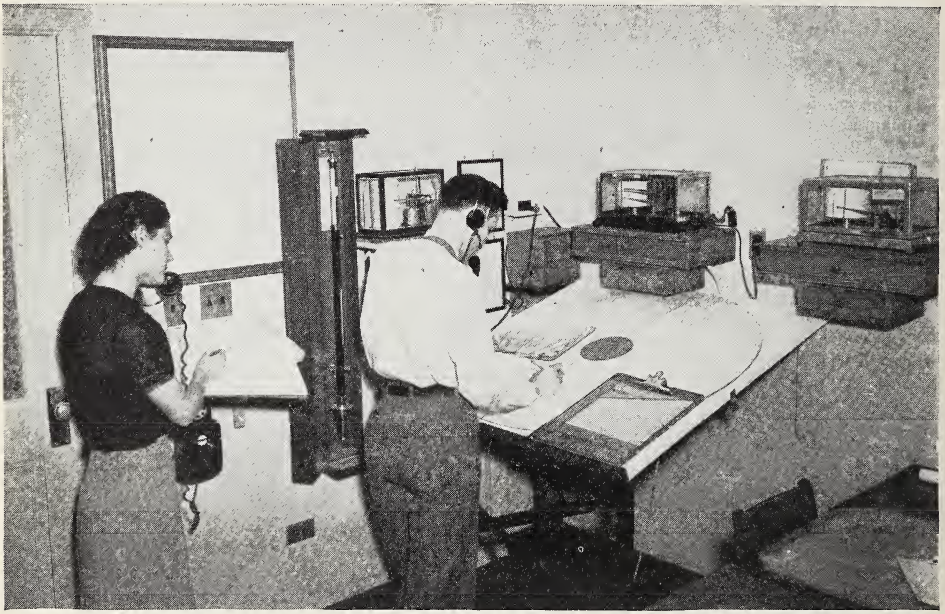


Fig. 20-6. A weather map of the type printed daily in the newspapers forecasts atmospheric conditions for a particular day.

to Revelstoke, B. C. About halfway there we would cross a stationary front and the clear dry air would change to slightly warmer and hazier air. At Revelstoke, we would find the temperature higher and the air not quite so clear as in Calgary. We would also find that the wind is blowing from the south. We are in another air mass, a warmer one which originated in the Pacific Ocean. If we had flown to Fort St. John we would find, shortly after our arrival, that the wind would become gusty and would shift from southwest to west or northwest and that the temperature would drop rapidly 20 to 30 degrees. This would be the result of the eastward movement of the cold front that is shown approaching from the northwest.

The weather map also shows three cyclones. We can see only a small portion of one in the upper left-hand corner. It can be recognized by the low pressure at its center. South of New York, however, we see a typical cyclone in its early stages, with a low pressure at its center. The cold front has just started to overtake the warm front and a small *occluded front* is shown. Such a front (there are 3 in Fig. 20-6) is indicated on weather maps by alternating warm- and cold-front markings on the same side of the front line.



Courtesy Trans-Canada Air Lines

Fig. 20–7. Meteorologist receiving weather information and recording data on a weather map.

When meteorologists forecast weather, they start by drawing a map like the one in Fig. 20–6, but more complex. Airlines and the Air Force have their own meteorologists to determine flying conditions along their routes (see Fig. 20–7). They use the information provided by the Weather Division. They also constantly receive reports by radio from their own planes on weather conditions along their flight routes. With this information they can make accurate maps and forecasts of the weather all along their routes.

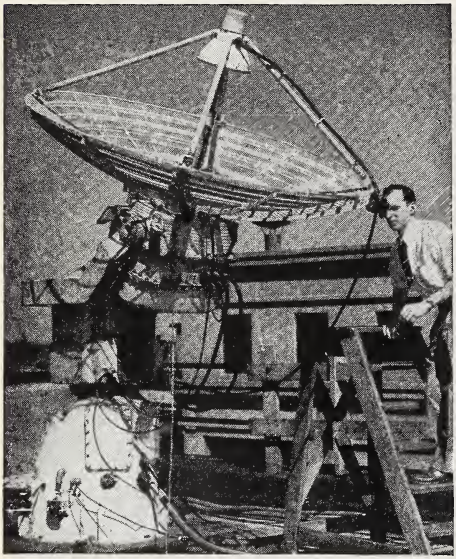
On long transoceanic flights planes do not always fly by the shortest geographical route. They can save both time and gasoline by what is called *pressure-pattern flying*. Before taking off, the pilot examines the pattern of the isobars on the weather map. By flying along the line of the isobars that surround anticyclones along his route, he nearly always has a tail wind to aid him.

Courtesy Trans-Canada Air Lines

Fig. 20–8. Trans-Canada Air Lines pilots consulting with a meteorologist about the kind of weather they may expect along their flight route.

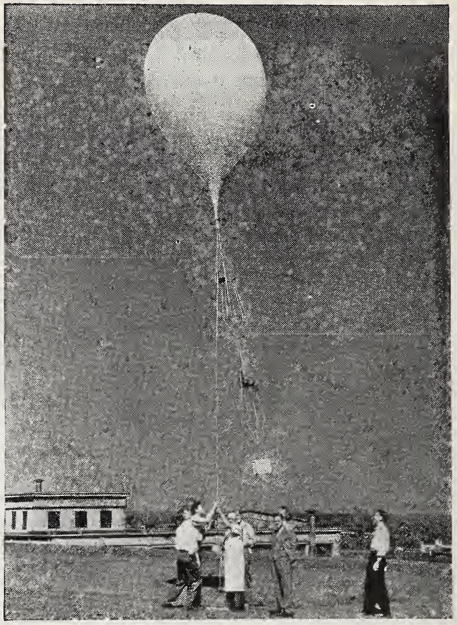
Air-Mass Analysis. Most modern weather forecasting is done by means of *air-mass analysis*. This requires knowing exactly what kind of air mass is overhead, where it comes from, and what is likely to happen to it in the near future. The forecaster must find out its temperature, humidity, and wind velocity and direction, not at the ground level but at altitudes of several thousand feet. At the ground level all these elements are greatly changed by the earth's surface. For example, a cold dry air mass that lies over warm moist ground tends to become warm and moist itself close to the ground. In addition, the wind will be reduced in velocity and changed in direction because of the friction of trees, hills, and buildings. At high altitudes the air is little affected by the ground below.

Such measurements are made at different levels, all the way up to the stratosphere, by means of a *radiosonde*. The radiosonde is a small box containing a thermometer, barometer, and relative-humidity indicator. It is carried up to the stratosphere by a helium-filled balloon. Also included in the box is a small radio transmitter that automatically transmits the temperature, pressure, and humidity back to the earth by means of coded signals. Radiosonde measurements, taken daily throughout the country, are used to make weather maps of the air at different levels above the ground. These maps are used by the meteorologist, in addition to the ground-level maps, to forecast weather by air-mass analysis.



Courtesy General Electric Co.

Fig. 20–9. This antenna records information on weather conditions from a balloon supplied with instruments and a radio transmitter.



Courtesy General Electric Co.

Fig. 20–10. These weather observers are preparing to release a radiosonde balloon.

THINGS TO REMEMBER

The *dewpoint* is the temperature to which the air must be cooled in order to produce condensation.

Hot days, when the relative humidity is high, are uncomfortable because perspiration does not evaporate rapidly enough to cool the body.

Isobars are lines on the weather map connecting points that have equal atmospheric pressure at the same time.

A *millibar* is equal to 0.0295 inches of mercury.

Weather maps give a complete picture of the weather over a large area.

Modern weather forecasting is accomplished by *air-mass analysis,* which requires a knowledge of temperature, humidity, and wind velocities and directions at high altitudes.

QUESTIONS

A

1. What is an anemometer?

2. What is an aneroid barometer?

3. Why are hot days when the relative humidity is high more uncomfortable than hot days when the relative humidity is low?

4. Point out the following things on the weather map, Fig. 20–6:

14·
9.00

(*a*) cold front
(*b*) warm front
(*c*) isobar
(*d*) anticyclone
(*e*) station circle
(*f*) a place where the weather is clear
(*g*) a place where snow is falling
(*h*) a low
(*i*) a place where the weather is cloudy

5. Give several instances in which property loss is prevented by accurate weather forecasting.

B

6. How may the dewpoint of the air be determined?

7. On the weather map in Fig. 20–6 locate the following:

(*a*) cold-air mass
(*b*) warm-air mass
(*c*) two places where the atmospheric pressure is 1008 millibars
(*d*) stationary front
(*e*) a place where the wind direction is south
(*f*) a place where the wind velocity is between 13 and 18 miles per hour
(*g*) a place where it is partly cloudy
(*h*) a cyclone

8. From the weather map in Fig. 20–6 try to forecast what the weather will be twenty-four hours later in the following cities: (a) Fort Nelson; (*b*) Gander; and (c) Winnipeg.

9. The mercury barometer reads 29.95 inches. How is this pressure expressed in millibars?

PROJECTS

1. *Observing the Weather.* At a regular time each day for a month record the following weather elements:

(*a*) temperature
(*b*) barometric pressure
(*c*) wind direction
(*d*) extent of clouds
(*e*) kind of clouds
(*f*) kind of weather
(*g*) rainfall

Calculate the following at the end of the month:

(*a*) average temperature
(*b*) average pressure (How close is it to 29.95 inches?)
(*c*) total rainfall
(*d*) number of cloudy days
(*e*) prevailing wind direction

The rainfall may be measured roughly by using a large tin can as a rain gauge. Set it horizontally in an exposed place where dogs and cats cannot drink from it. An ordinary ruler can be used as a measuring stick.

Wind direction may be determined by observing a weather vane or a flag.

2. *To Organize a Meteorological Club.* Start a meteorological club in your school. You can obtain simple weather instruments from any reliable instrument company or make them yourself. Take daily observations at a fixed time of the following weather elements:

(*a*) air temperature
(*b*) maximum daily temperature
(*c*) minimum daily temperature
(*d*) kinds of clouds
(*e*) state of weather (clear, partly cloudy, rain, fog, etc.)
(*f*) barometric pressure
(*g*) change in barometric pressure (rising or falling)
(*h*) wind direction and velocity
(*i*) amount of precipitation in last twenty-four hours

Weekly meetings can be held to discuss the weather during the past week and to compare it with the weather maps published during the week. (Weather guides and booklets on the weather are available from the Department of Transport, Meteorological Division, 315 Bloor St., West, Toronto, Ontario.) Clouds can be observed and identified at the weekly meeting.

The daily weather observations can be kept in a permanent file, and if there is no local weather bureau in your town, you may find that your newspaper will publish weekly summaries of precipitation, and maximum, minimum, and average temperatures provided by the club from their daily observations.

Your club or individual members may wish to join and carry on co-operative observations with the Amateur Weatherman's Association. Further details about this organization can be obtained by writing to Amateur Weatherman's Association, Washington, D.C.

Chapter 21

WHAT IS CLIMATE?

When we speak of the *weather,* we mean the day-by-day changes of temperature, rainfall, wind, clouds, humidity, and so on. *Climate,* on the other hand, refers to the average of these weather conditions in an area over a period of years. For example, if a cold front over Arizona produces rain for several days, we say the *weather* is wet. But because rain occurs infrequently in Arizona, and the total amount of rainfall each year is small, we say the *climate* of Arizona is dry.

The warmest climates are found near the equator and the coldest near the poles. Small islands, being entirely surrounded by water, have damp climates, whereas areas within a large continent, far from large bodies of water, generally have dry climates. Western China and Siberia, for example, have dry climates. The climate of a section of the world is determined by such factors as ~~the~~ ① direction of its prevailing wind, ② its nearness to the equator or poles, ③ its nearness to large bodies of water, and the ④ location of high mountain ranges.

Mountains as a Cause of Rain. As we have already pointed out, rain and snow fall only when a moist mass of air rises so that it expands and cools enough to cause condensation. This can occur not only along fronts but also when moving air is forced up over a mountain range.

Let us compare the climate of the western slopes of the Rockies with that of the eastern slopes. The prevailing winds that blow across British Columbia are westerly, bringing vast amounts of water vapor from the Pacific

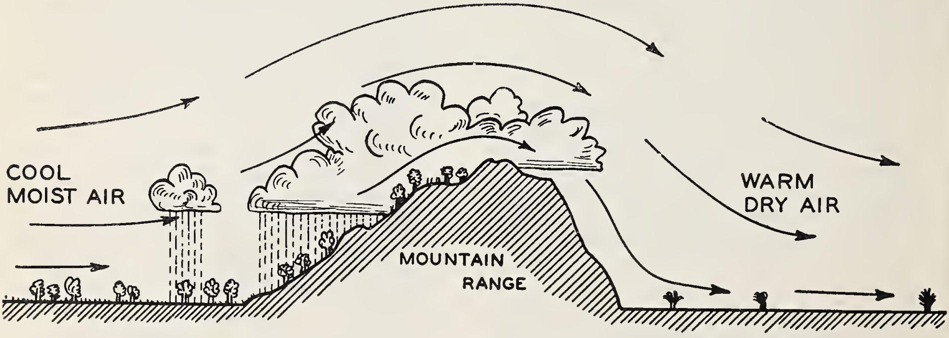


Fig. 21–1. Rain falls when warm moist air, forced to rise over a mountain range, expands and cools. However, the air gains heat from the condensation of the water vapor, and as it descends on the far side of the mountains, it is warm and dry.

Ocean. This moisture-laden air rises in flowing over the Rocky Mountains. In rising, it cools so that much of its water vapor condenses, resulting in a large amount of rainfall on the western slopes of the mountains. This rain water runs into the valleys of British Columbia, making them very fertile. Indeed these valleys are among the most fertile regions in Canada. By the time the air has passed to the eastern slopes of the mountains, it has lost much of its water vapor. Saskatchewan and Alberta are therefore dry. An extreme example is Death Valley, just east of the Sierra Nevada, which is the driest and hottest place in the United States.

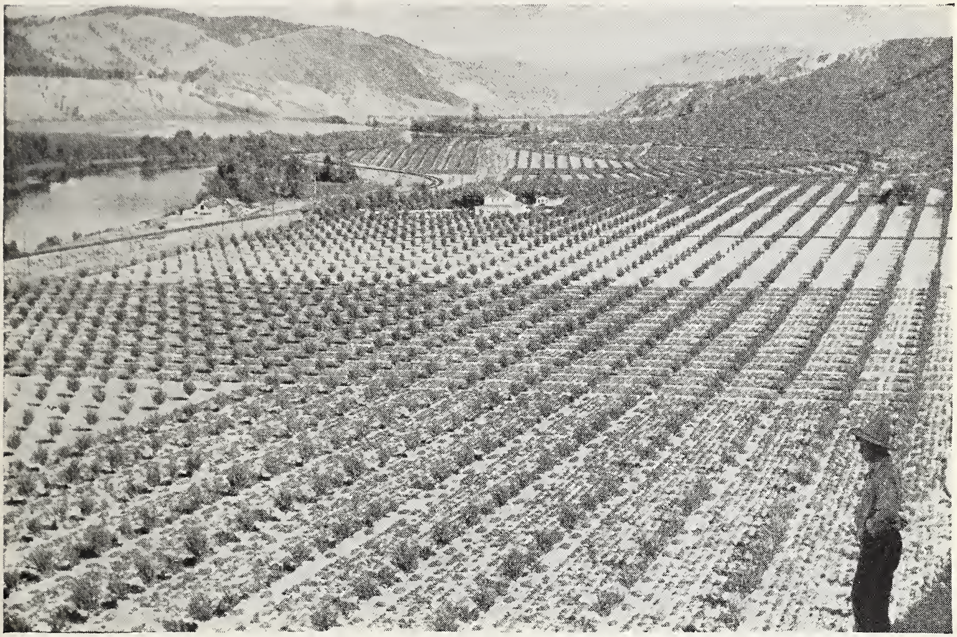

Courtesy National Film Board

Fig. 21–2A. Apple orchards in the fertile Okanagan Valley, British Columbia.

Monsoons. The *monsoon* is the name given originally to the seasonal prevailing winds in India. During the winter, the prevailing wind over the Himalayas in northern India is from the north. Since the area from which it blows is a large mass of land, this wind does not contain much moisture and it is cool. In the summer, the prevailing wind over the Himalayas is from the opposite direction; it comes from the south and brings large quantities of moisture from the Indian Ocean. It is a warm wind and makes India hot and humid during the summer. The most outstanding feature of this summer monsoon is the large amount of rain that falls on the southern slopes of the Himalayas. The strong moisture-laden wind from the Indian Ocean blows toward the highest mountain range in the world. The result is that nearly all the moisture is deposited among the foothills of the southern slopes of the Himalayas as the air is forced up over the mountains and cooled. It rains continuously for a whole season, and the heaviest rainfall in the world—nearly 500 inches a year—has been recorded there. More than 100 inches are usually recorded during each of the months of June, July, and August.

As one would expect, north of the Himalayas the climate is hot and dry in summer and cold and dry in winter. In this region is the famous Gobi Desert.

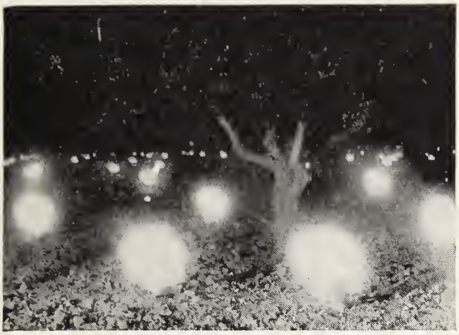
Courtesy U.S. National Park Service

Fig. 21–2B. Death Valley in southeastern California.

CONTROLLING THE WEATHER

Meteorologists and physicists sometimes dream of being able to control the weather so that every part of the world may always have good weather. If the arctic and antarctic regions could be warmed so that food could be grown there, or if the tropical areas could be tempered in their heat to make them more livable, many of the problems accompanying an increasing world population and an insufficient food supply would be solved. Today such control of the weather sounds rather fantastic, but progress is being made in this direction. Some familiar accomplishments represent first steps in the control of the weather. The first campfire that man made was an attempt to change the effects of the weather. The first attempts at irrigation practiced by the ancient Egyptians were efforts to moisten areas in which there was no rainfall. These early efforts to overcome natural deficiencies have been developed to the efficient heating and air-conditioning systems of modern buildings and to irrigation projects such as those in the Imperial Valley in California.

Weather Control in Orchards. Another form of weather control is the use of smudge pots to prevent the freezing of oranges in the orchards of Florida and California during a cold wave. At night when the weather is ab-



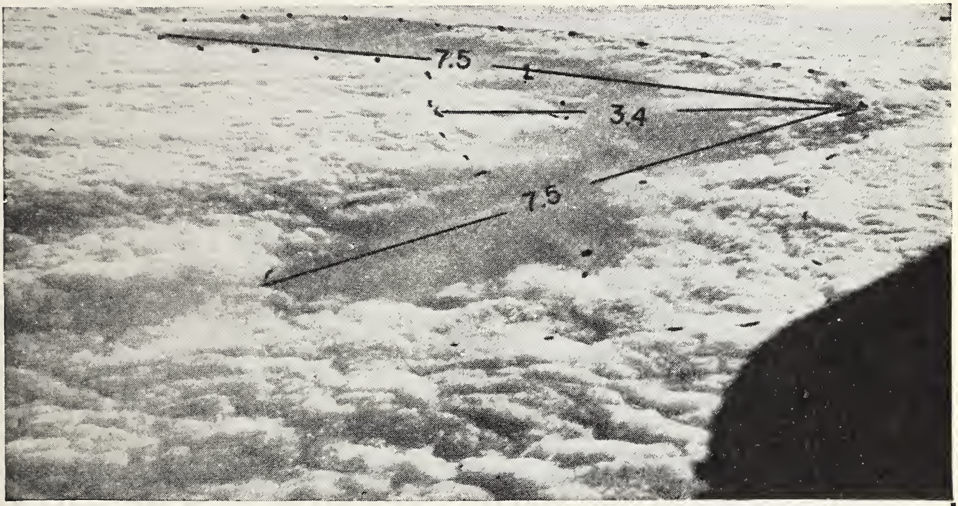
Medford Commercial Club, Medford, Oregon, from U.S. Weather Bureau

Fig. 21–3. Smudge pots used in an orchard to protect fruit trees from frost.

normally cool and the sky clear, the smudge pots are put out in the orchards. The oil burned in these pots produces large amounts of smoke. This smoke forms a cloud over the orchard which retains the heat on the ground.

In some orchards freezing temperatures close to the ground are prevented by means of large electric fans placed on ladders between the trees. These fans circulate the air and stir it up, so that the air near the cold ground is replaced by warmer air from above. By these methods, and by the timely warnings from the Weather Bureau, thousands of dollars' worth of citrus fruit are saved every year.

Fog Dispersal. Ever since the early days of flying, scientists have worked on methods of dispersing fog. Several methods have been used with some success. In one of these, large sound-generating machines are set up along the edge of a runway. When a plane wishes to land, the sound generators are turned on. They produce tremendous amounts of sound



Courtesy U.S. Army Signal Corps

Fig. 21–4. This 15-mile long, 3-mile wide L-shaped hole, roughly twice the area of Manhattan Island, New York City, was produced in a supercooled or icing cloud by seeding the cloud with dry-ice pellets. Since such a hole is free of dangerous icing conditions, an airplane could descend or ascend through it safely. It is estimated that by dry-ice seeding a plane could, within fifteen minutes, clear a hole large enough through which to ascend or descend. (The large dark area at the right is the tip of the wing of the plane from which the photograph was taken.)

energy of a pitch too high to be audible to the human ear. The sound vibrations produced in the air knock the fog droplets together until they form drops large enough to fall to the ground as a light rain, leaving the runway clear of fog until the plane has safely landed.

Making Rain. Rain and snow have been produced on a fairly large scale by the use of dry ice. In one method, an airplane flies through a dense cloud scattering small pellets of dry ice. As a result, droplets in the cloud join to form large drops of water which fall to earth. A few pounds of dry ice produce many tons of water in the form of precipitation. Silver iodide, which is easier to handle than dry ice, will produce the same effect.

THINGS TO REMEMBER

Climate is the average weather over a period of years.

Smudge pots are used to prevent freezing in orchards.

Small land masses surrounded by water have a *moist climate.*

Large land masses far from oceans have a *dry climate.*

A *monsoon* is a seasonal prevailing wind that blows from one direction part of the year and from the opposite direction the rest of the year.

Precipitation can be started by scattering such substances as dry ice or silver iodide in moisture-laden clouds.

QUESTIONS

A

1. Explain the difference between weather and climate.

2. What is a monsoon?

3. Where does the largest and most famous monsoon occur?

4. Where does the world's greatest rainfall occur?

5. What are smudge pots used for?

B

6. How do mountains cause rain?

7. Describe one method of dispersing fog.

8. How may precipitation be started in a cloud that is heavily saturated with water vapor?

9. Why is the area just east of the Sierra Nevada so dry?

10. Explain the causes of the heavy rains in India. Why do they not occur in winter?

11. What has caused the Gobi Desert?

12. Why does it never become very hot or very cold in Bermuda?

13. Why is it very hot in summer and very cold in winter in Saskatchewan?

REVIEW QUESTIONS ON UNIT 4

A

1. Name and describe three kinds of clouds.

2. What is an isobar?

3. Wind is the result of: (*a*) the expansion of ocean water; (*b*) the motion of the earth around the sun; (*c*) electricity in the air; (*d*) unequal heating of the earth's surface.

4. Why is there little wind in the doldrums?

5. What is meant by the term *dewpoint?*

6. Determine which of the following statements are true and which are false. Then correctly reword the false ones.

(*a*) The wet-bulb temperature is always higher than the dry-bulb temperature.

(*b*) Monsoons occur only in India.

(*c*) Warm air pushes back cold air, forming a warm front.

(*d*) An aneroid barometer contains mercury.

(*e*) An anemometer is used to show the direction of the wind.

7. Match each word in the left-hand column with the word it is most closely related to in the right-hand column.

thunderstorms	islands
warm front	fog
tornado	cumulonimbus clouds
moist climate	whirlpool of air
dew point	hazy air

8. Why does more rain usually result from a warm front than from a cold front?

B

9. Draw and label a diagram of a warm front.

10. Draw and label a diagram of a cold front.

11. How does the heat of condensation supply energy to: (*a*) a thunderstorm; (*b*) a hurricane?

12. Why does a hurricane rapidly die out when it starts moving over the land?

13. What is an occluded front?

SUGGESTIONS FOR FURTHER READING

A

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Unit 5

FIRE AND FUELS

22. WHAT IS FIRE?
23. OXIDATION
24. FIRES AND EXPLOSIONS
25. THE CONTROL OF FIRE
26. OIL AND ITS ORIGIN
27. COAL AND ITS ORIGIN
28. FUEL GASES
29. THE CARBON DIOXIDE CYCLE

Chapter 22

WHAT IS FIRE?

One important reason why man has become supreme on the earth is that he knows how to use fire. Indeed, civilization began when he learned to build a fire. With fire, primitive man cooked his food, made weapons, tools, and other articles, protected himself against wild animals, and generally made his life more comfortable.

The *cause* of fire, however, was a complete mystery to him; he could not answer the question, What is fire? He was therefore superstitious and frightened. When a flash of lightning started a forest fire he fled in terror believing it was caused by an angry supernatural being, a fire god intent on destroying him. Many primitive tribes worshiped a fire god, and sometimes they tried to appease him by sacrifices. The ancient Greeks tried to answer the question, What is fire? by legend or fanciful stories. They believed that Prometheus, a fire god and a friend of mankind, stole fire from heaven and gave it to men.

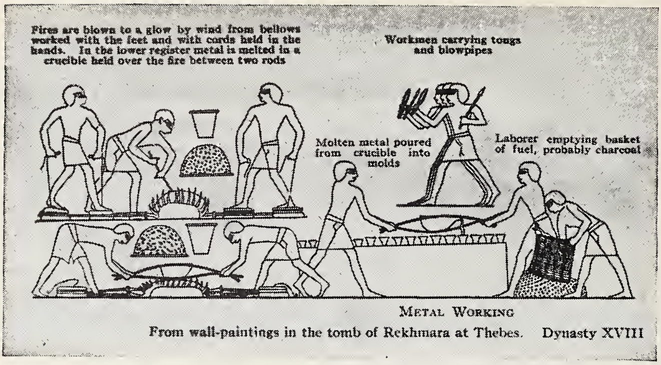
The cause of fire remained a mystery for many centuries. It was not until the end of the 18th century that Lavoisier, a French chemist, found the explanation. Lavoisier spent several years performing many scientific experiments on the problem of fire. His explanation was simple: *Fire is caused by a chemical reaction between the burning substance and the oxygen of the air.* Since Lavoisier's contribution to our knowledge of fire and burning is very important, we shall study it in some detail. Before doing so, however, let us turn back a few centuries and examine some of the earlier ideas.

Development of Chemistry. Chemistry is one of the oldest sciences; it began about 3000 B.C. For centuries it made little progress. During the Middle Ages, the chemist was interested mainly in converting other metals to gold. The foundations of modern chemistry were laid in the 17th and 18th centuries. In the 19th and 20th centuries chemistry has made astonishingly rapid advances.

Why were the foundations so long in being laid? Why has *modern* chemistry developed so rapidly? The early history of chemistry is, for the most part, a story of progress resulting from trial and error. There were few scientific theories to guide the experimenters. After centuries of effort, chemists learned the *scientific method*. Since this method has been in use, chemistry has advanced rapidly.

Early Egyptian Chemistry. The early Egyptians were practical people who wanted scientific knowledge because it gave them power and wealth.

Gold was found in Egypt, and as early as 3000 B.C. the Egyptians were expert goldsmiths. They were skilled in getting copper and lead from their ores. They were experts in glassmaking; in tanning; in embalming bodies; and in extracting dyes, oils, and drugs from plants. They discovered the beneficial and harmful properties of many drugs, and


Fires are blown to a glow by wind from bellows worked with the feet and with cords held in the hands. In the lower register metal is melted in a crucible held over the fire between two rods
Workmen carrying tongs and blowpipes
Molten metal poured from crucible into molds
Laborer emptying basket of fuel, probably charcoal

METAL WORKING

From wall-paintings in the tomb of Rekhmara at Thebes. Dynasty XVIII

Fig. 22–1. The Egyptians were skilled metallurgists.

this knowledge they passed on from generation to generation.

Egyptian chemists were either priests or temple workmen. Their laboratories were in the temples. The priest-physicians were also magicians, and the practice of medicine was accompanied by charms and chants. Chemistry did not rid itself of this Egyptian mysticism until the end of the 17th century.

The Greek Philosophers. The Greeks were not mystics like the Egyptians. They looked for logical explanations of natural phenomena. Some of their conclusions were incorrect, but many of their errors might have been discovered if their theories had been tested by experiments.

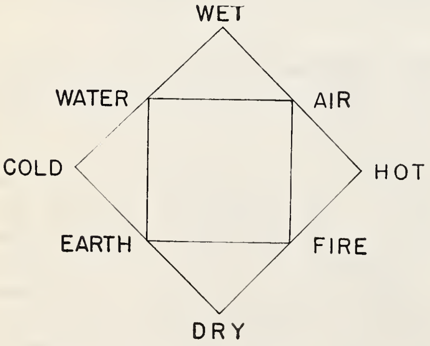


Fig. 22–2. The four fundamental elements according to Aristotle were earth, air, fire, and water.

Perhaps the greatest of the Greek philosophers was Aristotle (384–322 B.C.). He was the first great man of science. Aristotle believed that all substances came from one original "seed," and that the "seed" could be made to produce a variety of substances. As we shall see, modern scientists have a similar belief, but Aristotle went further with his theory when he said that one substance could be changed into another by varying the proportions of the "elements" in the substance—a process known as *transmutation*.

What were these "elements"? Aristotle believed that all matter was made up of four elements—earth, air, fire, and water. These "elements" determined the four fundamental properties of all substances—hotness, coldness, dryness, and wetness. Water is cold and wet; earth is cold and dry; fire is hot and dry; air is hot and wet. This concept of an element has long since been discarded. But it survives in an old phrase, "the fury of the elements."

Although often incorrect, the Greek ideas influenced scientists for centuries. Indeed, the idea of transmutation was accepted by chemists for more than a thousand years, until the end of the 17th century.

Science in the Moslem Empire. When the early Romans defeated the Greeks and extended their empire into Egypt, many Greek and Egyptian scholars fled to Persia and Syria, where they continued their scientific work. Then, in the 7th century came the rise of the Arabs, inspired by their prophet Mohammed. The Arabs overran Egypt, Persia, and Syria, and then spread westward through North Africa and into Spain. The Arabs encouraged the scholars to continue their scientific studies, and some notable advances were made. Bronze, silver, copper, and iron came into use as common metals; nitric and sulfuric acids were discovered; and even papermaking was developed to a high degree.

One very important result of the Moslem invasion was that the "chemical art" was brought to Europe. The Moors founded the University of Cordova, in Spain, in the 8th century. Scholars from England, France, and Germany were attracted to this school. They stimulated a wide interest in the science which in medieval times developed into *alchemy*.

Alchemy. The European alchemists were influenced by the religious ideas of the Egyptians and by the transmutation theory of the Greeks. Their beliefs show that they were not scientists. They believed that nature was simple and that all natural processes moved toward perfection. Man, for example, strove toward perfection; a seed gained perfection in the plant. Similarly, a metal strove toward perfection. Gold, they argued, is the perfect metal. It does not tarnish in air, and it is not affected by acids as other metals are. Gold is the noble metal; other metals are base. The alchemists believed that the differences between metals were due only to maturity or age. They tried, therefore to hasten the slow process of nature and convert base metals into gold.

They believed that a seed had a body and a spirit and that a metal must also have a body and a spirit. The body of the seed must be destroyed before it can bring forth the plant; so, they said, a base metal must be destroyed before it can yield the perfect metal, gold.

How can metals be destroyed? Their answer was, "By fire." But the alchemists also believed in a powerful transmuting agent which they called the *philosophers' stone*. No one had seen this stone, but the magic substance was believed to be a fine powder.

In their search for the philosophers' stone, they heated and distilled eggs, bones, plant extracts, and animal excretions, often with minerals or base metals. The method of heating was extremely important. Once begun, the heating must be continued without interruption. Some alchemists heated their concoctions for seven days (the biblical time required to create the world), others for forty days, but the more zealous ones heated them for a year and a half. The shape of the vessel, too, was supposed to have a subtle influence on the heated substances. The most popular apparatus was a philosophers' egg, an egg-shaped crucible which was the symbol of the creation of new life.

During the 16th and 17th centuries many people were engaged in the futile search for the philosophers' stone and gold. Kings had their alchemists in laboratories near their palaces; serfs used cellars and caves as laboratories. In their dismal dens the alchemists toiled continuously, sweating day and night at their furnaces. The picture on page 200 shows a weary alchemist sleeping by his unfinished notes as the morning light streams into his cellar laboratory. The alchemists continued their search for many centuries, but they neither converted base metals into gold nor discovered the philosophers' stone. Theirs was the longest futile search in scientific history.

Why was the alchemist's search so fruitless? The alchemist used methods that were unscientific. He made assumptions, which he never questioned, about the simplicity of nature and the tendency of all things to move toward perfection. All his work was founded on these false assumptions, so that he made no progress. In the end he became discouraged, but he eventually learned the most important precaution that a scientist must take: Verify by experiment the assumptions on which the investigation is based.

The Phlogiston Theory. The first chemical *hypothesis*, or theory, called the *phlogiston theory*, came at the end of the 17th century. Fire, to the ancients, had always been impressive and mysterious, and it was natural that the first chemical theory should be an attempt to explain burning, or combustion. During the Middle Ages it was known that some metals could be "won" from their ores simply by heating an "earth" (which today we call an ore or an oxide) with charcoal. The extraction of iron from ore had been known to the Egyptians and Syrians as early as 1500 B.C. These early experimenters knew that

iron "earth" + charcoal → iron metal

In looking for a theory to explain this metal-winning process, scientists argued somewhat as follows: The earthy material (which was called a *calx*) obtained from nature is "simpler" than the metal made by man. Therefore, when the metal is formed, something must be added to the calx. This "something" they called *phlogiston*.

Elihu Vedder, Courtesy of the Brooklyn Museum

Fig. 22–3. The alchemist.

In other words, their "explanation" of the metal-winning process was

calx + phlogiston → metal

No one had seen phlogiston; it was an elusive substance. However, the early scientists believed that substances like oil, charcoal, and sulfur were rich in phlogiston because they burn easily. Since charcoal is rich in phlogiston, they continued, it will give up phlogiston to a calx and so form a metal:

calx + phlogiston from charcoal → metal

On the other hand, they said, when metals "burn," a calx is formed and phlogiston escapes:

metal → calx + phlogiston

This theory was confirmed by experiments. For example, when the metal copper was heated, a black powder—the calx of copper—was formed:

copper → calx of copper + phlogiston

When the calx was heated with charcoal, the metal was again obtained:

calx of copper + phlogiston → copper

Let us perform the same experiments.

Demonstration 22–1. To Form Copper Calx.

Hold a piece of copper foil by a pair of tongs and place it just above a small Bunsen flame. Notice that the foil turns dark. After it has cooled, scrape it with a knife to show that the black calx can easily be removed.

Demonstration 22–2. To Form Copper from Copper Calx.

Thoroughly mix 5 grams of copper calx (copper oxide) and 0.4 gram of activated charcoal. Pour the mixture into a dry test tube. Support the tube on a stand and heat the mixture strongly by a Bunsen flame. Eventually the mixture begins to glow. Then discontinue the heating. When the test tube has cooled, notice that the black powders have changed to a dark red powder, which is copper.

The phlogistonists appeared to be on the right track, for their theory had been confirmed, in part at least, by experiment. If, as the theory states, a metal loses phlogiston in forming the calx, we would expect the calx to weigh less than the metal. Let us test the theory by weighing the metal and the calx.

Demonstration 22–3. To Show That Iron Increases in Weight in Forming the Calx.

Place some reduced powdered iron (about 5 grams) in an evaporating dish. Weigh the dish. Place the dish on a tripod or stand and heat it for about two minutes. When it is cool, weigh it again. Notice the marked increase in weight

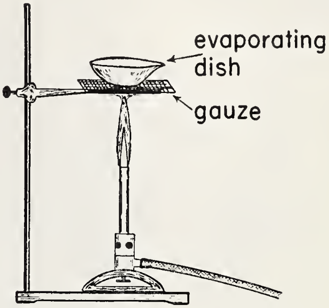


Fig. 22–4. Iron increases in weight when heated.

Failure to account for the fact that a metal gains weight when it is burned was a serious flaw in the phlogiston theory. Some supporters of the theory tried to explain the increase in weight by stating that phlogiston was a peculiar substance that had a negative weight. Thus the escape of phlogiston in burning would account for the increase in the weight of the metal.

The phlogiston theory was not borne out by all experimental facts and was therefore replaced by a better one. Other theories have suffered a similar fate. Unless a theory can be modified to explain new facts as they are learned, it must be rejected.

Lavoisier's Theory of Combustion. Living in the 18th century, the French scientist Lavoisier inherited the phlogiston theory from earlier scientists, but he did not accept it. The phlogiston theory assumed that burning was due to something within a substance that was expelled when the substance was burning. Lavoisier, however, believed that air had something to do with burning; that when a substance burned something was added to it, not removed from it. What experimental evidence had Lavoisier to support his ideas?

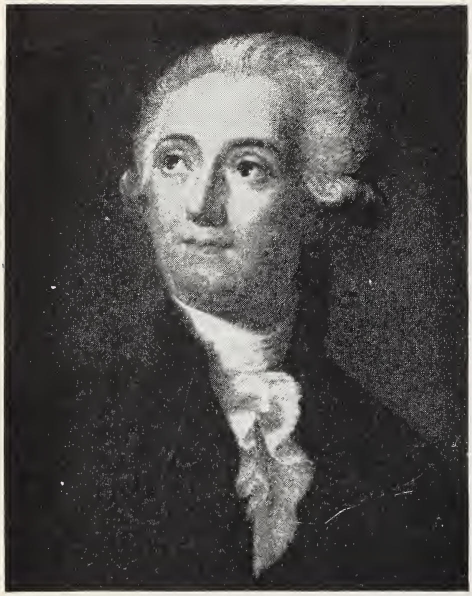


Fig. 22–5. Antoine Laurent Lavoisier (1743–1794), the founder of modern chemistry.

Lavoisier put some mercury into a retort the neck of which was bent so that there was free access to the air in a bell jar which was supported in a trough of mercury. He then heated the retort over a slow charcoal fire, as shown in Fig. 22–6. A red calx of mercury began to form in the retort and at the same time the mercury in the bell jar began to rise. At the end of twelve days the mercury stopped rising in the bell jar and about one-fifth of the air had been removed from it. Lavoisier concluded that the reaction was completed.

What had taken place? Lavoisier said that some of the mercury in the retort had "burned" because it had combined with the active gas in the air, which he later called *oxygen*, to form a calx or oxide of mercury:

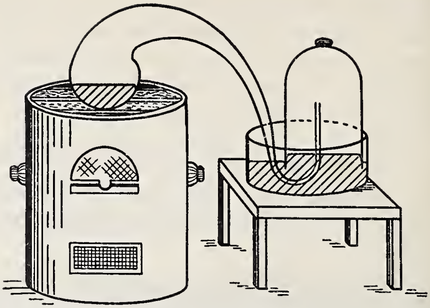


Fig. 22–6. Lavoisier heated mercury on a slow charcoal furnace.

mercury + oxygen → mercury calx
or mercury oxide

This was a revolutionary idea. There was no mention of phlogiston; instead, *oxygen was the essential element in combustion, or burning.* How could Lavoisier prove this? His experiment was certainly incomplete; more evidence was needed to support his theory. Was it possible, for instance, to recover the "lost" oxygen and show that its volume was the same as that of the gas which had been removed from the retort? With this question in mind, Lavoisier devised the following experiment to recover this "lost" oxygen.

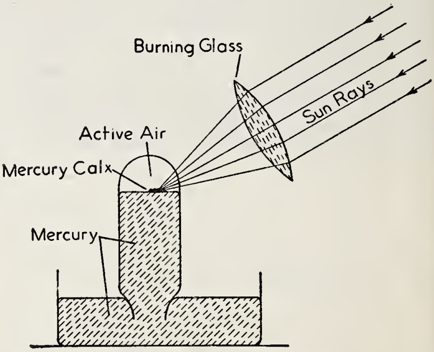


Fig. 22–7. Lavoisier decomposed mercury calx by the sun's heat.

He arranged the apparatus as shown in Fig. 22–7. Liquid mercury was poured into a dish and the calx supported on the surface of mercury in an inverted glass vessel from which most of the air had been removed. The sun's rays were then concentrated upon the calx of mercury by means of a lens, or burning glass as it was called. The result was that the mercury calx was decomposed to form mercury and a gas. The volume of the gas was the same as the volume of the gas that had been removed from the retort in the earlier experiment. Moreover, this gas strongly supported burning. A candle, for instance, burned much more intensely in this gas than in air. Lavoisier therefore concluded that

mercury calx (or mercury oxide) → mercury + oxygen

With this experiment Lavoisier completed his investigation. Singlehanded he had disproved the phlogiston theory and replaced it with the modern theory of combustion. Many of the scientists of his day were too conservative to accept the new ideas and clung to the old phlogiston theory. Lavoisier, however, had started a revolution in scientific procedure.

You will recall that the increase in weight that always accompanies the change from the metal to the calx could not be explained by the phlogistonists. It is easily explained by Lavoisier's theory. Can you give this explanation of the increase in weight?

Modern chemistry began with the work of Lavoisier. Lavoisier is regarded as one of the world's greatest chemists. Unfortunately he was a victim of the French Revolution, which followed the American Revolution by a few

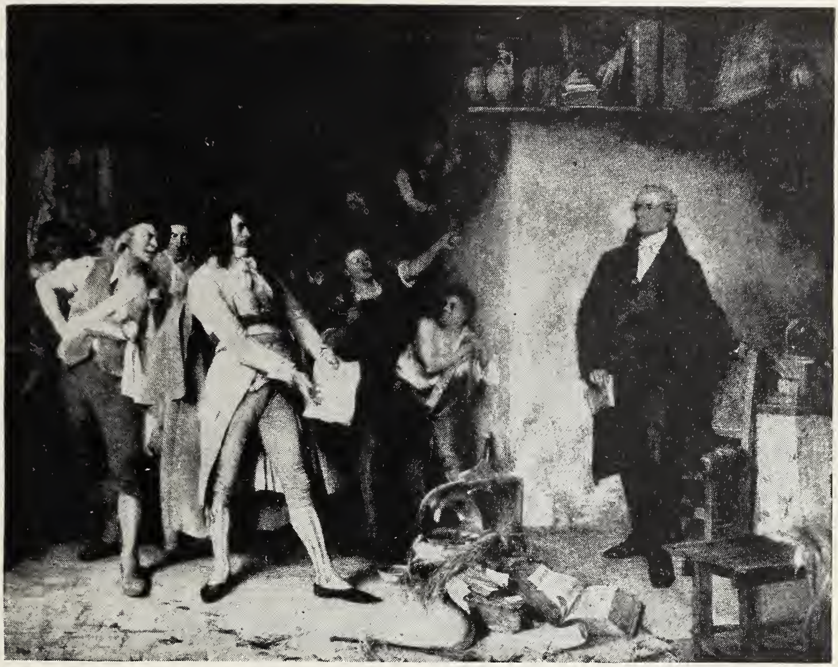


Fig. 22–8. The arrest of Lavoisier.

years. An aristocrat, he was charged with collecting illegal taxes from the French people. Although it was pointed out at his trial that he was a famous scientist and should be spared, the president of the court replied, "Nous n'avons pas besoin de savants" ("We have no need of scholars").

Lavoisier was executed by the guillotine, and his body was dumped into an unmarked grave. A fellow scientist named Lagrange bitterly remarked, "It required but a moment to cut off his head and perhaps a hundred years will not produce another like it." Time has proved this to be a prophetic remark.

THINGS TO REMEMBER

The *early Egyptians* were interested not in chemical theory but only in technical applications.

Aristotle was the greatest of the Greek philosophers. He believed that there were only four elements—earth, fire, water, and air.

Transmutation is the process of changing one element to another.

The *Moslems* brought the "chemical art" to Europe. They founded the University of Cordova in Spain.

The *alchemists* tried to convert base metals into gold.

The *phlogiston theory* tried to explain burning. It was discarded because it could not explain all the experimental facts.

Lavoisier gave the *modern explanation of combustion*, or burning. He stated that when a substance burns it combines chemically with the oxygen of the air.

QUESTIONS

A

1. Who were: (*a*) Mohammed; (*b*) Aristotle; (*c*) Lavoisier; (*d*) Prometheus?

2. Approximately when did the following scientists live: (*a*) Aristotle; 384-322 BC (*b*) Lavoisier? 1743-1794

3. State the meaning of the following: (*a*) calx; (*b*) phlogiston; (*c*) noble metal; gold (*d*) philosophers' stone.

4. Tell why the phlogiston theory was: (*a*) proposed; (*b*) discarded.

5. Write, in your own words, Lavoisier's explanation of combustion.

B

6. State some of the scientific ideas of Aristotle.

7. Explain why the alchemists failed to achieve any positive results.

8. By what experimental evidence did Lavoisier support his explanation of combustion? Explain.

PROJECT

Obtaining Oxygen from Mercury Calx or Oxide. Place a little red calx of mercury in a test tube. Clamp the tube to a stand and heat the bottom of the tube with a small Bunsen flame. At first the oxide turns black and then mercury vapor condenses on the side of the tube. Hold a glowing splint of wood just inside the test tube. The end of the splint should burst into flame, proving the presence of oxygen. If the heating is continued, the calx disappears altogether. Where does the mercury come from? Where does the oxygen come from? Is mercury calx a compound or an element? Why does the mercury vapor condense? Could the phlogistonists have explained the escape of oxygen from mercury calx?

Chapter 23

OXIDATION

According to Lavoisier, combustion, or burning, is a chemical reaction between a combustible substance and oxygen. This type of reaction is called *oxidation*. Before discussing oxidation, however, you must understand the terms *chemical reaction, combustible substance,* and *oxygen.*

A Chemical Reaction. We have already used the term *chemical reaction* several times without defining it. What, exactly, is meant by this term? A chemical reaction or a chemical change takes place either when two substances combine to form a compound—*combination,* or when a compound is decomposed into simpler substances—*decomposition.*

The iron-sulfur reaction described on page 20 is an example of combination. Several other observations could have been made at that time. We shall therefore repeat the experiment, this time using zinc and sulfur.

Demonstration 23–1. A Chemical Reaction between Zinc and Sulfur.

Prepare a mixture of powdered zinc and powdered sulfur, using 6 grams of zinc and 3 grams of sulfur. After you have thoroughly mixed the ingredients, pour the mixture on an asbestos sheet supported on a tripod. Heat the mixture with a flame, removing the flame as soon as the reaction starts. Notice that a great deal of heat is liberated as the reaction proceeds.

This is a combination type of reaction in which the elements zinc and sulfur have combined to form a compound called zinc sulfide. The chemical change can be represented by the equation:

$$\text{zinc} + \text{sulfur} \rightarrow \text{zinc sulfide} + \text{heat}$$

Or, using symbols:

$$Zn + S \rightarrow ZnS$$

Most chemical reactions, though not all, result in the liberation of heat. In this case so much heat is released that the mixture becomes red-hot.

Another thing to notice is that the zinc powder is gray and the sulfur is yellow. The zinc sulfide is yellow when hot and white when cold. *When a chemical change takes place, entirely different substances are formed.*

Sulfur combines readily with zinc and iron. Indeed, sulfur combines with all metals except gold. The "resistance" of gold to sulfur was one reason why the alchemists regarded gold as the perfect metal.

Oxygen. We now are going to observe some reactions between oxygen and other substances, that is, combustion. Oxygen is present in the air, but only 20 percent of the air is oxygen. If we wish to obtain pure oxygen, we must prepare it by chemical means. The simplest method of doing this is to get it from a compound called potassium chlorate. When potassium chlorate is heated, it decomposes and oxygen is released. A chemical reaction of this kind is called a *decomposition* reaction.

In practice a black powder called manganese dioxide is mixed with the potassium chlorate in order to decompose the latter more easily. A substance like manganese dioxide, which speeds the reaction but is itself not affected chemically, is called a *catalyst.*

Demonstration 23–2. Preparation of Oxygen.

Place a mixture of 4 grams of potassium chlorate and 2 grams of manganese dioxide in a test tube, and arrange the apparatus as shown in Fig. 23–1. Force one end of a bent glass tube through a stopper and insert the stopper in the test tube, dipping the other end of the tube under water in a trough. Fill two bottles with water, close them with glass covers, and invert them under water in the trough. Remove the glass covers.

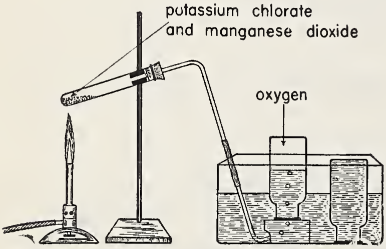


Fig. 23–1. Preparation of oxygen.

Heat the mixture with a small flame. After the first few bubbles have escaped, place the outlet of the tube under one of the bottles and collect the gas, which is oxygen. When the water in the bottle has been displaced, close the bottle with the cover, lift it out of the water, and stand it upright on the bench. Now fill the other bottle with oxygen in the same way.

Combustible Materials. Combustible materials may be solids, such as coal, wood, phosphorus, and even sulfur; liquids, such as gasoline, kerosene, and alcohol; or gases, such as hydrogen, acetylene, and coal gas. First we shall burn two of these solids, sulfur and phosphorus, in the bottles of oxygen we have prepared.

Demonstration 23–3. The Burning of Sulfur and Phosphorus in Oxygen.

Place a little sulfur in a combustion spoon and heat the sulfur until it burns. Notice the blue flame. Now remove the cover from one of the bottles and plunge the burning sulfur into oxygen. The sulfur burns much more intensely in oxygen than in air.

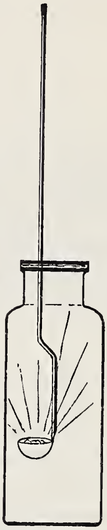


Fig. 23–2. Burning sulfur in a combustion spoon.

Caution: Molten sulfur causes painful burns. To prevent an accident, therefore, after the burning stops, plunge the hot spoon with the remaining sulfur into the trough of water.

Now repeat the experiment using red phosphorus instead of sulfur. Notice again that the red phosphorus burns much more intensely in oxygen than in air. Moreover, the substance formed is a white powder.

When a substance burns in oxygen, an *oxide* is formed. *An oxide is a compound of oxygen and another element.* In the first case, an oxide of sulfur, called sulfur dioxide, is formed; in the second, an oxide of phosphorus, phosphoric oxide is formed. These reactions are examples of *oxidation,* oxygen being the *oxidizer.*

The reaction between oxygen and sulfur can be shown by the equation:

sulfur + oxygen → sulfur dioxide

Or, in symbols:

$$S + O_2 \rightarrow SO_2$$

The subscript 2 after the symbol for oxygen means that the oxygen molecule contains two atoms of oxygen.

Caution: Sulfur dioxide is a pungent gas. Do not inhale it.

In both experiments a great deal of heat is given out, as is proved by the flame. The heat

2. Do te— for oxygen

evolved is often included in the equation of the reaction:

phosphorus + oxygen → phosphoric oxide + heat

Or, in symbols:

$$P + O_2 \rightarrow P_2O_5 + \text{heat}$$

When pure oxygen is used, the combustible substance has five times as many oxygen molecules to combine with as it would have in the same volume of air, for the air is only one-fifth oxygen. The burning is therefore more intense. For this reason, oxygen, not air, is used when a flame of very high temperature is needed. Acetylene, for example, will combine with oxygen, and the resulting flame is so hot that it can be used for cutting metals (see page 256).

Hydrogen. Hydrogen can easily be obtained by decomposing acids, such as hydrochloric acid and sulfuric acid. All acids are compounds containing hydrogen. If they are decomposed by a metal such as zinc, hydrogen gas is liberated. As already stated in Chapter 3, hydrogen is the lightest gas. It is also an important fuel gas, as can be proved by collecting a bottleful and burning it.

Demonstration 23–4. Preparation and Burning of Hydrogen.

Place some pieces of zinc in a bottle or generator. Fit up the apparatus as shown in Fig. 23–3. Pour enough *dilute* sulfuric acid down the thistle tube to cover the zinc.

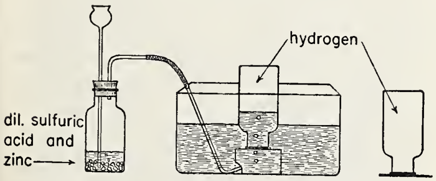


Fig. 23–3. Preparation of hydrogen.

The first bubbles to escape from the generator are a mixture of air and hydrogen. *Caution:* This is an explosive mixture and should be handled with care. Do not collect the gas in the bottle until all traces of air have been removed. As a safety test, first fill a test tube with water and collect a tubeful of escaping gas by displacing the water. Hold the mouth of the tube downward, with the open end near a Bunsen flame, as shown in Fig. 23–4. A loud pop shows that air is being mixed with the hydrogen. Repeat this test until there is only a gentle pop. It is then safe to proceed.

Now collect a bottle of hydrogen. When all the water has been displaced, raise the bottle, mouth down, with one hand and at the same time thrust a burning taper well into the bottle with the other hand.

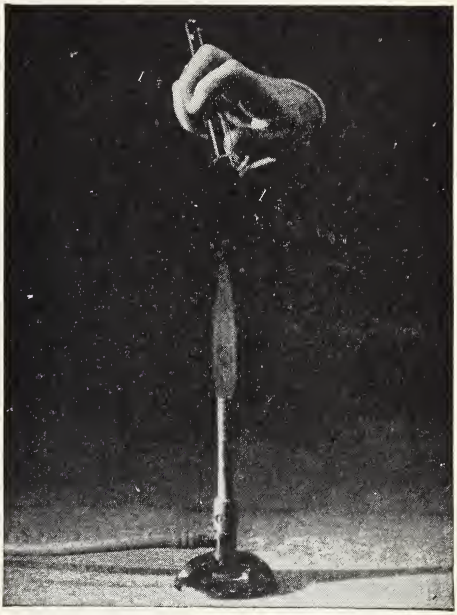


Fig. 23–4. The safety test for hydrogen.

Notice that the hydrogen burns at the mouth of the bottle, but that the burning taper is extinguished by the hydrogen in the bottle. In other words, we may state that *hydrogen burns, but, unlike oxygen, it does not support burning.*

The Hydrogen Flame. If a stream of hydrogen is forced through a narrow opening or jet, it will burn with a steady dark blue flame. A *flame is always a sign of a chemical reaction.* In this experiment it is a reaction between hydrogen and the oxygen of the air. Expressed as an equation, the reaction is

hydrogen + oxygen → hydrogen oxide + heat

or

$$2H_2 + O_2 \rightarrow 2H_2O$$

The number 2 placed *before* the hydrogen symbol means that two hydrogen molecules take part in the reaction. The formula $2H_2$ represents four *atoms* of hydrogen, whereas O_2 represents two atoms of oxygen. The formula $2H_2O$ represents a total of six atoms.

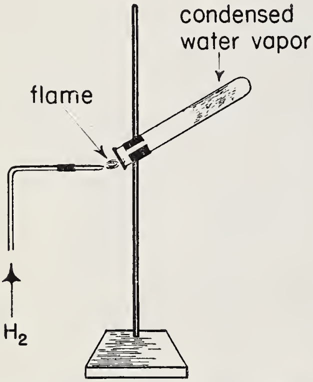


Fig. 23–5. Water vapor, formed in the hydrogen flame, condenses inside the test tube.

The common name for hydrogen oxide is water vapor. Water vapor is a *product of combustion,* and it escapes into the air.

Demonstration 23–5. The Hydrogen Flame.

Disconnect the glass delivery tube at the rubber connector and in its place attach a glass jet. After making certain that there is no air in the generator, light the escaping hydrogen. Allow the flame to burn just inside a dry test tube as shown in Fig. 23–5. The droplets of water that collect on the inside wall of the tube prove that water vapor is formed *in* the hydrogen flame.

A Candle Flame. A candle is made of paraffin wax, which is a mixture of *hydrocarbons.* A *hydrocarbon* is a compound of hydrogen and carbon. A wick or cotton thread runs through the center of the candle. The wick acts as a pipeline to convey the molten paraffin wax from the top of the candle into the flame, where it vaporizes and burns. A candle flame, as shown in Fig. 23–6, consists of three zones: (1) a dark central zone around the wick, (2) a large white luminous zone that supplies the light, and (3) a bluish almost invisible fringe surrounding the white zone, visible near the base.

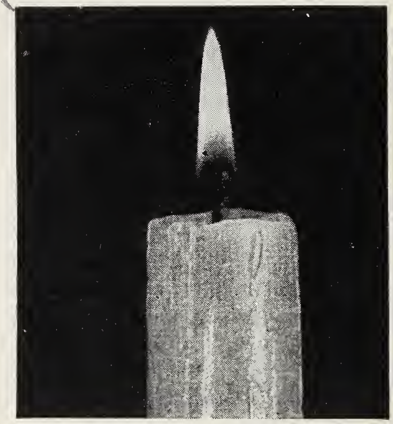


Fig. 23–6. A candle flame.

The *dark central zone* consists of unburned paraffin vapor. The vapor is unburned because the oxygen of the air does not enter this region. It is easy to show that there is no burning in the central zone. If a matchstick is held in the flame for a second and then withdrawn, in the central portion the wood remains unburned, but on either side of this area the match is charred by the flame.

The *luminous zone* is caused by white-hot minute particles of carbon. The equation for the reaction in this portion of the flame is:

paraffin or hydrocarbon + oxygen → water vapor + carbon + heat

In other words, the hydrogen of the hydrocarbon is oxidized to water vapor, but there is not enough air in this zone to convert the carbon of the hydrocarbon to carbon dioxide. The luminous zone is therefore a region of *incomplete combustion*. The presence of the carbon in this zone is shown by the deposit of soot that appears when a piece of white china or porcelain is held in the flame.

The *outermost zone* is surrounded by air, so that the carbon in this region is completely burned to carbon dioxide; that is, *complete combustion* occurs in this zone. We can prove the presence of carbon dioxide by showing that this gas turns limewater milky.

Demonstration 23–6. To Prove That Carbon Dioxide Is Formed in the Candle Flame.

Hold an inverted test tube over the candle flame for a few moments. Pour some limewater into the test tube, close the tube with a stopper, and shake it. Notice the formation of a milky substance, which proves the presence of carbon dioxide.

A Gas Burner. The candle is a fair source of light but a poor source of heat. A great deal of the heat of a burning candle is wasted because much of the carbon escapes unburned. For complete combustion the air outside the flame is insufficient; air must be supplied to the flame itself. This idea was first applied to a gas burner about a hundred years ago by a German scientist named Bunsen.

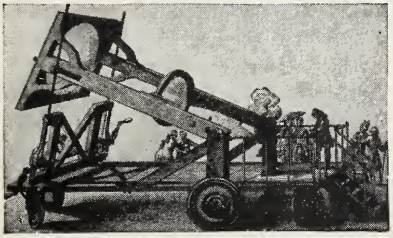


Fig. 23–7. Lavoisier's large burning glass.

Before Bunsen invented a coal-gas burner, it was difficult to obtain a supply of heat for even simple experiments. Sometimes candles were used, but they did not give much heat and the sooty deposit was objectionable. Frequently a coal stove was used, and occasionally even the heat of the sun. Fig. 23–7 shows a device used by Lavoisier in which the sun's rays were concentrated on an object by means of lenses.

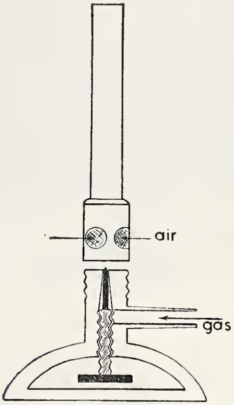


Fig. 23–8. Section of Bunsen burner.

The modern Bunsen burner consists of four parts, as shown in Fig. 23–8: (1) the base, (2) a jet and valve to control the gas supply, (3) the barrel where the gas and air mix, and (4) openings at the base of the barrel to admit air.

The mixture of air and gas burns at the top of the barrel. If the air ports are closed, the flame is *luminous*, like the candle flame, because of the presence of white-hot particles of carbon. This flame gives light but little heat; the hand can be passed through it without discomfort. It is therefore of little use in the laboratory where heat, not light, is usually needed. If the air ports are opened properly, the carbon particles are completely burned to carbon dioxide and the flame is *nonluminous*. This hot, nonluminous flame is usually referred to as the Bunsen flame.

The Bunsen flame, as shown in Figs. 23–9 and 23–10, consists of four zones: (1) a dark central zone containing unburned gas and air, (2) an inner greenish zone where burning first begins, (3) a large dark blue zone of intense burning, and (4) an outer light blue fringe of complete combustion. The hottest part of the Bunsen flame is just above the green cone in the center of the flame. In this region copper, which has a melting point of nearly 1100° C., can be melted as was shown in Demonstration 13–4.

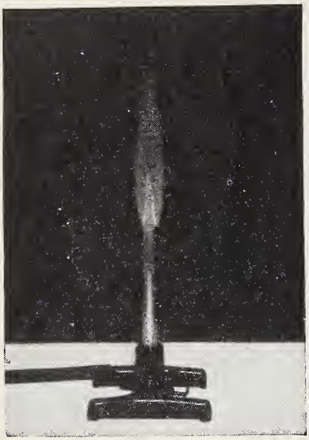


Fig. 23–9. Burner and flame.

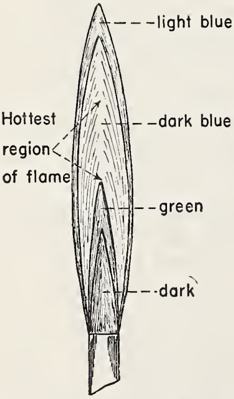


Fig. 23–10. The zones of a Bunsen flame.

Demonstration 23–7. To Show That the Central Zone Contains Unburned Gas.

Hold the wide end of a glass jet about four inches long in the dark central zone of the Bunsen flame, and light the escaping gas at the jet. It is clear that the unburned gas flows from the central zone through the tube.

Household Heaters. Although the Bunsen burner was invented as a convenient source of heat for the laboratory, it has been adapted to supply heat in the home. The gas cooking stove, for example, operates like a Bunsen burner. In the stove gas and air are mixed in a pipe, and the gas mixture is burned at the openings in a ring burner. The ring burner provides a number of small flames arranged in a circle so that the heat will be spread rather than concentrated in one spot.

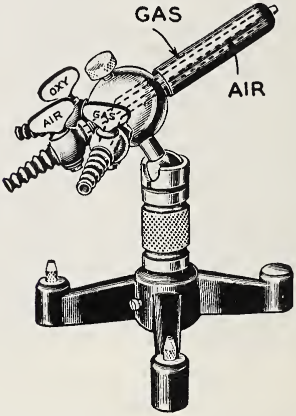


Fig. 23–11. A blowtorch or blast lamp.

The flames of the ring burner should not be luminous. A luminous flame indicates that insufficient air is entering the gas mixture. Thus fuel is being wasted and the flame is not as hot as it should be. Moreover, a good deal of soot is deposited on the articles being heated. The flame of the kitchen burner should therefore be examined from time to time to determine whether the opening that admits the air needs adjusting.

A Blowtorch or Blast Lamp. If air or oxygen is forced under pressure into a hydrogen flame, the rate of burning is increased and the temperature of the flame is raised. An apparatus (Fig. 23–11) that makes this possible is called a *blowtorch* or *blast lamp*. Notice that the gases are not mixed in the barrel, as in a Bunsen burner, but in the jet.

In the oxyhydrogen torch hydrogen is admitted into the middle tube and ignited at the opening. Oxygen is then slowly admitted and the flame becomes smaller and hotter. The oxyhydrogen flame has a temperature of about 2500° C. It is used for cutting and welding metals. A still higher temperature is obtained in the oxyacetylene flame (see Chapter 28). Even if ordinary fuel gas and air are used in the blowtorch, the temperature of the flame is high enough (at least 1500° C.) to melt iron.

Demonstration 23–8. To Burn Steel Wool in a Blowtorch.

Attach a blowtorch to a supply of gas and compressed air. Turn on the gas and light it. Admit the air until the burner is roaring. Hold a piece of steel wool in the flame and observe that it burns away in a shower of sparks.

Matches. It was not long after Lavoisier's time that chemical methods for producing fire were discovered. In the early part of the 19th century a Frenchman named Chancel put a a mixture of potassium chlorate and sugar, bound together by glue, on one end of a strip of wood. He then dipped this covered tip into concentrated sulfuric acid. When he removed it, it burst into flame. This was the first match. The acid reacted with the sugar to form carbon, and the carbon combined with the oxygen of the potassium chlorate and burned. Since the potassium chlorate supplied the oxygen, it was the oxidizer. This match was both awkward and dangerous.

Shortly afterward the first *friction match* was made. The tip consisted of a mixture of potassium chlorate and phosphorus or sulfur. This mixture was ignited by rubbing the tip on sandpaper, the heat of friction being sufficient to start the reaction and ignite the tip. Friction matches were dangerous because they were set on fire too easily, often as a result of accidental friction.

The modern *safety match* was invented in the middle of the 19th century. This match is usually tipped with a mixture of potassium chlorate and antimony sulfide. Safety matches ignite only when they are rubbed on a specially prepared surface consisting of red phosphorus and powdered glass, usually found on the outside of the box or package in which they are sold.

oxidiz
combu
mate

We accept the match today without thinking of its importance to modern civilization. A century and a half ago fire was commonly produced from the sparks obtained by friction between flint and steel. It was Lavoisier's theory of combustion that gave the clue to the discovery of chemical methods of making fire. And the match is an example of the benefits given to mankind once a theory has been established.

THINGS TO REMEMBER

Combustion is a chemical reaction between a combustible substance and oxygen.

Two main types of chemical reactions are *combination* and *decomposition*.

Heat is released in most chemical reactions.

Pure *oxygen* can be prepared by decomposing potassium chlorate.

Oxidation is a reaction between oxygen and another element.

An *oxide* is a compound of oxygen and another element.

Hydrogen is prepared by decomposing an acid by a metal. sulfuric acid – zinc

Hydrogen burns, but does not support burning; *oxygen supports burning,* but does not burn.

A *flame* is a sign of a chemical reaction.

A *hydrocarbon* is a compound of hydrogen and carbon.

The *luminosity of a candle flame* is due to white-hot particles of carbon.

A *test for carbon dioxide* is that it turns limewater milky.

The *modern safety match* has a tip of potassium chlorate and antimony sulfide and a rubbing surface of red phosphorus and powdered glass.

QUESTIONS

A

1. Complete the equations for the following chemical reactions:
  - (*a*) iron and sulfur →
  - (*b*) phosphorus and oxygen →
  - (*c*) hydrogen and oxygen →

2. Explain the following terms: (*a*) combustion; (*b*) hydrocarbon; (*c*) incomplete combustion; (*d*) oxidation.

3. What is the essential element in: (*a*) an acid; (*b*) an oxide?

4. Give an example of: (*a*) a combination reaction; (*b*) a decomposition reaction.

5. Label each of the following as a combination reaction or a decomposition reaction:
  - (*a*) mercuric oxide → mercury + oxygen
  - (*b*) mercury + oxygen → mercuric oxide
  - (*c*) paraffin + oxygen → carbon dioxide + water vapor

6. Name the oxidizer and the combustible materials in a modern safety match.

B

7. Hydrogen is usually prepared by the reaction between a metal and a dilute acid. Draw a labeled diagram of the apparatus you would use to collect a bottle of the gas.

Where does the hydrogen come from—the acid or the zinc? Give a reason for your answer.

8. (*a*) Write a symbolized equation for the reaction in the hydrogen flame.
  - (*b*) Give the meanings of the numbers you have used in the equation.
  - (*c*) State the *number* of atoms that take part in the reaction shown in the equation.

9. A burning taper is plunged into an inverted jar of hydrogen. (*a*) Explain what happens. (*b*) Give two important conclusions that can be drawn from this experiment.

10. Describe experiments which prove that both carbon and carbon dioxide are formed in the candle flame.

11. Draw a nonluminous Bunsen flame and label the zones.

12. If the flame of the cooking stove in your home has a luminous tip, would you suspect insufficient fuel gas or air? *Why* should you correct the air-fuel supply? *How* would you correct it?

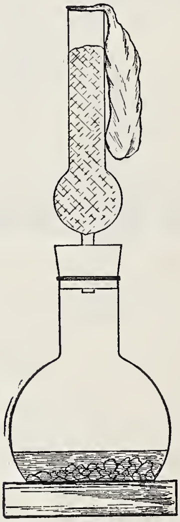


Fig. 23–12. A hydrogen balloon.

PROJECT

Inflating a Balloon with Hydrogen. To show that hydrogen is lighter than air, place some zinc in a flask and then pour in enough *dilute* hydrochloric acid to cover it. The acid is at once decomposed and hydrogen bubbles escape. Place some cotton in a tube to catch the acid spray, and to one end of the tube attach a rubber balloon. Insert the other end of the tube in a cork stopper and fit the stopper into the flask as shown in Fig. 23–12.

The escaping hydrogen inflates the balloon. Detach the balloon from the tube, tie the opening with thread, and then release the balloon. It will rise to the ceiling.

Chapter 24

FIRES AND EXPLOSIONS

In Chapter 23 we considered several chemical reactions: the reaction between zinc and sulfur, the burning of hydrogen, the burning of a candle, and the burning of coal gas. In all these experiments heat had to be applied to start the reaction. The mixture of zinc and sulfur was heated until a glow was observed; the candle, the hydrogen, and the coal gas were all lighted to start the burning. At ordinary temperatures, zinc will not react with sulfur, nor will paraffin wax react with oxygen. In other words, substances must be heated to their *reaction temperatures* or *kindling temperatures* before a reaction takes place.

Kindling Temperature. *The kindling, or ignition, temperature of a substance is the temperature to which the substance must be heated before it starts to burn.* Every combustible substance has its own kindling temperature. The kindling temperatures of phosphorus, gasoline, and ether are relatively low, and these substances are therefore highly inflammable. Wood and coal, on the other hand, have much higher kindling temperatures; they require strong heating before they will burn. Kerosene has a higher kindling temperature than gasoline, and it does not burn when a lighted match is dropped into it.

Demonstration 24–1. Kindling Temperature of Kerosene.

Pour some kerosene into a beaker and then drop a lighted match into it. The match goes out and the kerosene does not burn. Why?

Now pour the kerosene into a metal bowl and heat it over a Bunsen flame for a few seconds. Again drop a lighted match into the kerosene. This time it burns. Why?

Finally, move the bowl containing the burning kerosene in a tray containing ice and water, as shown in Fig. 24–1. The flames are soon extinguished. Why?

You have probably already thought out the answers to these questions. In the first experiment the burning match does not ignite the kerosene because the kerosene is not at its kindling temperature. The Bunsen flame heats the kerosene so that the burning match can raise it to its kindling temperature, and the kerosene therefore bursts into flame. The ice and water cool the kerosene below its kindling temperature, and the flames are extinguished even though there is still kerosene in the bowl.

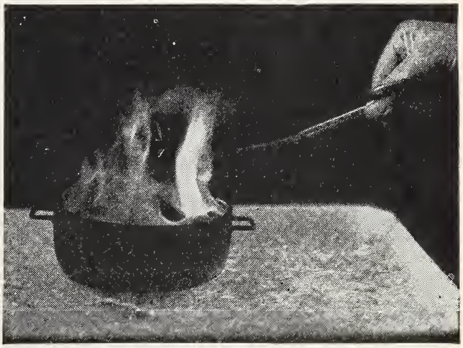
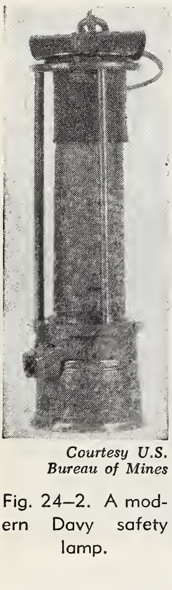


Fig. 24–1. The kerosene flame is extinguished when the bowl is moved around in ice and water.

This demonstration illustrates an effective way of controlling a fire and extinguishing a flame; namely, cooling the combustible substance below its kindling temperature. Thus, if explosive gases are kept below their kindling temperatures, they are not dangerous. This principle was employed in the Davy safety lamp, which was designed to provide safe illumination in coal mines.

The Davy Safety Lamp. Until the early part of the 19th century few safety precautions had been taken in coal mines. The miners, especially in England, worked under extremely dangerous conditions. They made their own tallow candles from sheep fat and used them to give light while they were working in the mines. When the burning candles were carried into a pocket of *firedamp*, as the explosive mine gas is called, the result was disastrous. There were many serious explosions in the English coal mines, and the loss of life was so heavy that the mine owners appealed to Sir Humphry Davy to investigate the explosions and to find a means of preventing them. Davy studied samples of firedamp taken from the mines, and in only two weeks he found a solution. He first discovered the cooling power of wire gauze.



Courtesy U.S. Bureau of Mines

Fig. 24–2. A modern Davy safety lamp.

In the experiment on page 141 we saw that metal gauze over a Bunsen burner rapidly conducts the heat of a flame along the strands of wire so that the unburned gas is kept below its ignition temperature. The conductivity of the gauze therefore has a cooling effect, so that the gas which passes out through the gauze does not burn. It was this principle that Davy discovered and immediately applied in constructing a safety lamp.

The Davy lamp is an oil lamp with a piece of iron wire gauze completely surrounding the flame, as shown in Fig. 24–2. As the hot gases pass out through the gauze they are cooled by conduction below the ignition temperature of the inflammable gases outside. The lamp can also be used to detect the presence of firedamp. Firedamp passes in through the metal gauze, where it is ignited and changes the color of the flame. The Davy safety lamp has been adopted by miners of many nations and has undoubtedly saved thousands of lives. Miners in the United States today use an electric light instead of the Davy lamp.

Dust Explosions. *Dust* consists of fine particles of solid material suspended in the air. If the solid is combustible material, the dust may be highly inflammable.

Demonstration 24–2. To Compare the Inflammability of a Block of Wood with That of a Chip of Wood.

Hold a block of wood over the flame of a Bunsen burner for a few seconds. The wood will probably char but not burn. Now cut off a splinter of wood from the block and hold this in the flame. The splinter burns at once. Why should the splinter burn but not the block? What is the important difference between the two?

Before answering these questions, let us investigate the burning of an inflammable dust, such as flour or lycopodium powder. Lycopodium is a flowerless herb called clubmoss. The spores, found on the leaves of the plant, are called lycopodium powder, a highly inflammable substance.

Demonstration 24–3. The Burning of a Powder.

Attach a ring burner (or a Bunsen burner) to a stand. Place 3 or 4 grams of lycopodium powder in a calcium chloride tube to which a piece of rubber tubing has been attached, as shown in Fig. 24–3. Light the burner and then blow the powder through the flame. The powder burns instantly with a spectacular flash.

These two experiments with wood and powder prove that *the smaller the pieces of com-*

bustible material, the more rapidly they burn. The smaller the pieces become, the greater their contact with the oxygen in the air. Since the air is in contact with only the faces of the heated block of wood, the heat is not sufficient to start it burning. If a sliver or splinter of wood is heated, burning starts at once because relatively more of its surface is in contact with the air. Since the particles of dust have still greater surfaces in contact with the air, they burn violently once they have been heated to their kindling temperature.

Combustible particles are always a fire hazard, and precautions should be taken against this risk. The metals magnesium and aluminum, used in the construction of airplanes, are examples of this danger. When these metals are tooled during construction, the hot dusts that are formed are highly inflammable; they have caused many factory fires. The fire hazard can be reduced by sucking the metal dusts into a bag to prevent them from escaping into the air.

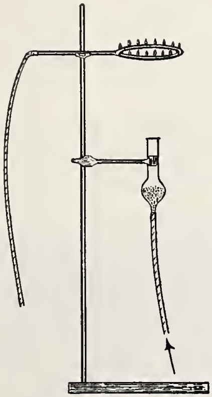


Fig. 24–3. The burning of a powder.

The inflammable nature of magnesium dust can be shown by throwing a little magnesium powder into a Bunsen flame; the powder ignites instantly with a white flash. *Caution:* Use only a very small amount of magnesium powder.

Spontaneous Combustion. In all these examples the inflammable dusts ignite only when they are raised to their ignition temperatures by heat from an outside source. Unfortunately some dusts and vapors reach their ignition temperatures and burst into flame without outside aid. When this happens, *spontaneous combustion* is said to have taken place.

Coal stored on ships, for example, has been known to catch fire by spontaneous combustion. When coal is being transported by sea, the constant rolling of the ship causes pieces of coal to rub against one another and make coal dust by friction. The coal particles, which are particles of carbon, slowly react with the oxygen of the air to form carbon dioxide:

$$\text{carbon} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{heat}$$

or $$C + O_2 \rightarrow CO_2 + \text{heat}$$

If there is not enough ventilation to carry away the heat of reaction, the temperature rises until the kindling temperature is reached, and the coal dust bursts into flame. Joseph Conrad, in the story called *Youth*, wrote a thrilling account of a fire started by the spontaneous combustion of coal on a sailing ship in the Indian Ocean.

Oily rags left in a badly ventilated place, such as a cupboard or closet, for example, may also be a source of spontaneous combustion. Since oil is a hydrocarbon, the following reaction takes place between oil vapor and oxygen:

$$\text{hydrocarbon} + \text{oxygen} \rightarrow \text{water vapor} + \text{carbon dioxide} + \text{heat}$$

If the heat released in the reaction is enough to raise the oil to its kindling temperature, a fire results.

Of all the fires caused by spontaneous combustion, however, probably the most common and serious ones occur in grain elevators. Since flour and grain dusts are highly inflammable, strict precautions must be taken against the danger of fire, either from spontaneous combustion or from sparks caused by friction in the machinery.

The ignition of hay in a barn or in outdoor stacks is another example of spontaneous combustion. Since the heat is liberated well *inside* the haystack, it is not caused by oxidation. It is due, instead, to the action of bacteria that decompose the hay and, in doing so, liberate heat enough to start a fire.

Gas Explosions. Every inflammable gas will explode with air under suitable conditions. Hydrogen and oxygen in the right proportion, for instance, form an explosive mixture. The explosive nature of such a mixture can be shown by confining the gases in a soap bubble and then igniting them.

Demonstration 24–4. Oxyhydrogen Explosion.

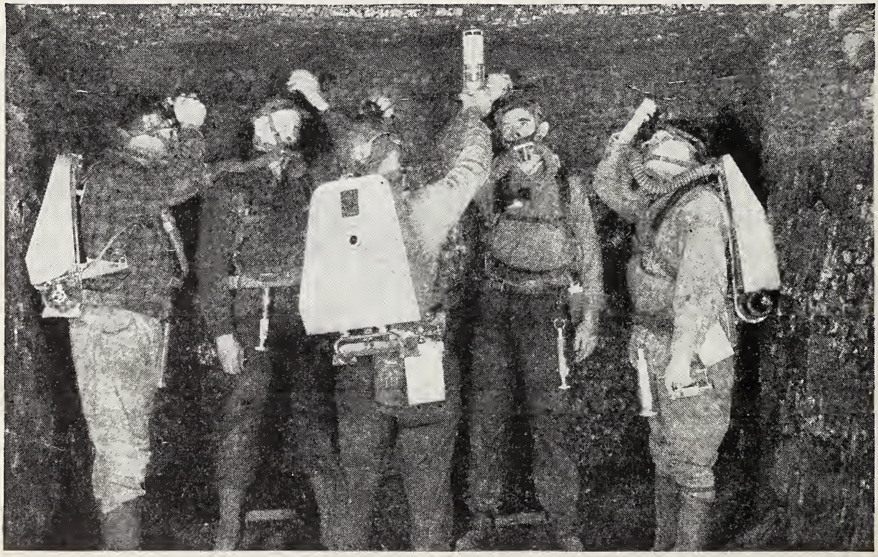
Prepare hydrogen and oxygen by the methods already described. By means of rubber tubing, attach the outlet tubes to a Y or T tube so as to mix the gases. Direct the stream of the oxygen-hydrogen mixture into a small quantity of soap solution in an iron mortar or metal dish. When a few soap bubbles have formed on the surface, *remove the tube conducting the mixed gases at least two or three feet from the dish.* Tie a wax taper to a long stick and ignite it. Now touch the bubbles with the burning taper and the bubbles will explode with a loud noise. *Caution:* The outlet tube must be kept well away from the flame; otherwise a dangerous explosion may result. The explosion in a soap bubble is, of course, quite harmless.

The chemical action that takes place is

hydrogen + oxygen → water vapor + heat

or $$2H_2 + O_2 \rightarrow 2H_2O + \text{heat}$$

The heat of the reaction causes a sudden and considerable expansion of the water vapor which develops an explosive force.



Courtesy U.S. Bureau of Mines

Fig. 24–4. A crew testing for explosive firedamp by examining the flame of a Davy lamp. Notice that the crew members are blocking off the light from the light bulbs on their helmets.

A gas explosion does not always result in a loud noise, however; in most explosions in coal mines there is little noise.

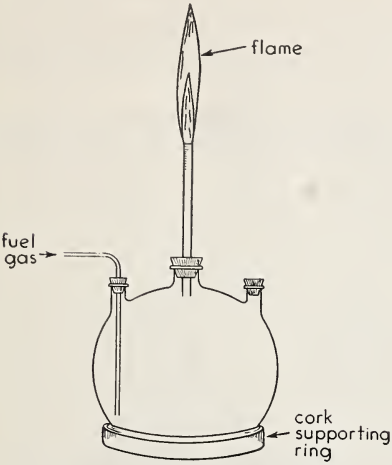


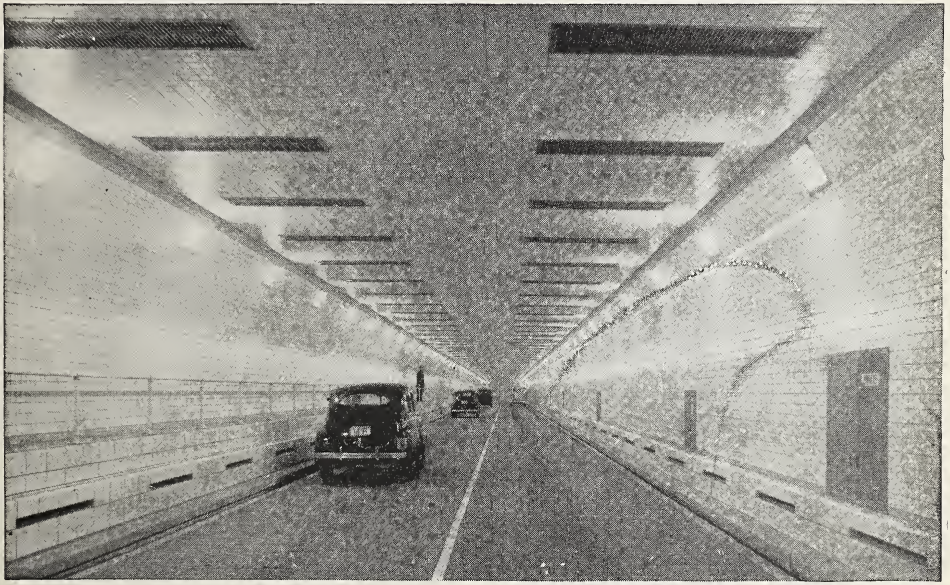
Fig. 24–5. A coal-gas explosion.

Demonstration 24–5. A Coal-Gas Explosion.

Arrange a three-hole, round-bottom flask as shown in Fig. 24–5. Close the right-hand opening with a rubber stopper and admit fuel gas through the tube in the left-hand opening. Allow the gas to escape from the center tube for 5 or 10 seconds. Then ignite it. Notice that the gas burns with a luminous flame.

Now remove the stopper from the right-hand opening and then *immediately* turn off the gas supply. Air now begins to enter the flask, causing the flame to become nonluminous. As the gas supply is used up, the flame gets smaller and smaller, until eventually it travels down the tube and into the flask, which instantly fills with flame.

This is a typical coal-mine explosion, except that in the mine the explosive gas is firedamp. There is not enough oxygen in the mine to cause complete combustion of the firedamp, so some carbon monoxide as well as carbon dioxide is formed. The carbon mon-



Courtesy Triborough Bridge and Tunnel Authority, N.Y.

Fig. 24–6. Queens Midtown Tunnel, New York. Fresh air enters by the ducts above the curb, and stale air is withdrawn through the rectangular ports in the ceiling.

oxide, which the miners call *afterdamp,* is very poisonous and more deadly than the explosion itself.

Not all gas explosions are harmful, however. If controlled and made to do work, as in the internal-combustion machine, they can be of great service to mankind.

The Internal-Combustion Engine. An internal-combustion engine is a device for igniting a mixture of gasoline vapor and air and using the force of the explosion to do work. It is called an *internal*-combustion engine because combustion takes place *inside* the cylinder. (Is there an *external*-combustion engine?)

carbon
hydrogen
oxygen

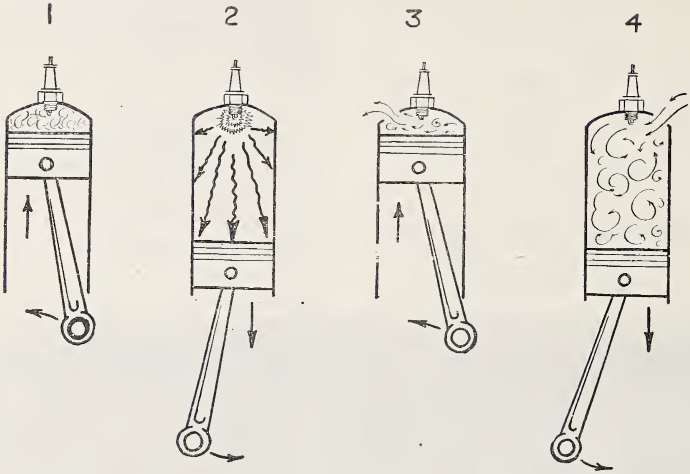


Fig. 24–7. Explosion of gases in a cylinder.

In this engine gasoline is forced through a nozzle in the carburetor and vaporized. The gasoline vapor is then mixed with air, and the mixture is led into the cylinder, where it is ignited by a spark from the spark plug in the cylinder head.

Gasoline is a mixture of hydrocarbons, one of which (hexane) has the formula C_6H_{14}. It reacts with the oxygen of the air according to the equation:

gasoline + oxygen → carbon dioxide + water vapor + heat

or $C_6H_{14} + O_2 \rightarrow CO_2 + H_2O + \text{heat}$

The formula C_6H_{14} means that one molecule of hexane contains 6 atoms of carbon and 14 atoms of hydrogen.

The heat of combustion causes the gases to expand, and the pressure of the expanding gases drives the piston down the cylinder, as shown in Fig. 24–7. The method by which the motion of the piston is converted into useful work, as in driving an automobile, is discussed in Chapter 31.

In reality, the oxygen in the gas mixture is hardly sufficient to convert all the carbon to carbon dioxide, and some carbon monoxide is always formed. In fact, the exhaust gases may contain as much as 7 percent carbon monoxide. This is a dangerously high proportion, and the exhaust gases may become exceedingly poisonous if the engine is allowed to run for some time in a closed garage.

Tunnels through which a great many automobiles pass must be well ventilated to prevent a dangerous accumulation of carbon monoxide. In the Lincoln and Holland tunnels, under the Hudson River in New York, carbon monoxide is removed by powerful electric fans. (See Fig. 24–6.)

EXPLOSIVES

When you hear the word *explosives*, you probably think of shells, bombs, and torpedoes used in warfare. But explosives also help man in peaceful pursuits. The invention of explosives saved a great deal of manual labor, because the forces developed in chemical reactions can be made to do work. Indeed, gunpowder is one of the greatest inventions; it enables man to blast iron ore out of the mountains and coal out of underground seams. It helped bring about the age of coal and steel.

Gunpowder, or Black Powder. Gunpowder was the first explosive used. It was invented in the 13th century and had a very important effect on human progress. For almost 600 years it remained the only explosive. Man soon discovered that it could be used in warfare to project rocks and cannon balls, and it was first used for this purpose in the 14th century. Before the discovery of gunpowder, battles were fought under the leadership of knights in armor mounted on horseback. Since their armor was no defense against projectiles propelled by gunpowder, the methods of warfare had to be changed.

Gunpowder is a mixture of potassium nitrate (often called saltpeter), charcoal, and sulfur. When it is heated, a brisk chemical reaction takes place. Potassium nitrate contains oxygen. The oxygen reacts with the charcoal to form carbon dioxide and carbon monoxide, and reacts with sulfur to form sulfur dioxide. Nitrogen and a solid residue (potassium oxide) are also formed.

The use of gunpowder for military purposes depends on several of its important properties. First, it burns very easily. Secondly, the potassium nitrate in it supplies all the oxygen necessary for burning. Thus, because gunpowder does not need the oxygen of the air for combustion, it can burn in an enclosed space, such as the barrel of a gun, for example. Moreover, since the temperature of the burning gunpowder is about 5000° F., the expanding gases can eject objects with great force.

In the early days, to fire a gun the gunner first rammed gunpowder into the muzzle and into a hole in the rear of the barrel. He then inserted the cannon ball. He ignited the powder in the hole, which in turn touched off the main charge in the barrel. There were several disadvantages in the use of gunpowder. The clouds of smoke that followed the explosion at once revealed the position of the gun to the enemy. Also, the solid residue in the barrel weighed almost half as much as the gunpowder. This clogged the gun, and the barrel had to be cleaned even during battle. Firing a gun was a slow process; during a rainstorm the powder became so wet that it was almost impossible to fire it.

In spite of its disadvantages, gunpowder, or black powder, was used in warfare for more than four centuries; it was not replaced by smokeless powder until the latter part of the 19th century.

During the Napoleonic Wars sulfur was obtained from the volcanic regions in Sicily; charcoal was obtained by heating wood. The production of potassium nitrate was, however, a more serious problem. This compound was made from stable manure by a process that took several months. Napoleon required all the farmers in conquered territories to convert their compost heaps into potassium nitrate and deliver their quotas to him.

Until the time of the American Revolution the American colonies supplied charcoal to England. Entire forests were burned down in order to supply charcoal for gunpowder and potash for soap.

Demonstration 24–6. The Burning of Gunpowder.

Grind *separately* and then mix thoroughly about 7.5 grams of potassium nitrate, 1.5 grams of charcoal, and 1 gram of sulfur. Place the mixture on a piece of asbestos supported on a tripod, and ignite it with a Bunsen flame. Notice the clouds of smoke and the large amount of solid residue. *Note:* In the open, gunpowder burns rapidly but without explosive effects. Though this experiment is quite safe, it should be performed near a hood or in a well-ventilated room.

Modern Explosives. The first modern explosives were invented about a hundred years ago. They are of two kinds—*high explosives* and *low explosives*. High explosives burn much faster and therefore develop a much greater shattering force than low explosives. Moreover, most high explosives are more sensitive to shock than low explosives. For these reasons the two types of explosives have different uses. Gunpowder and smokeless powder are low explosives; trinitrotoluene (usually called TNT), dynamite, and nitroglycerine are high explosives. The various uses of high and low explosives are illustrated in the firing of a shell (see Fig. 24–8.). The whole shell consists of two parts, the case and the shell, or projectile.

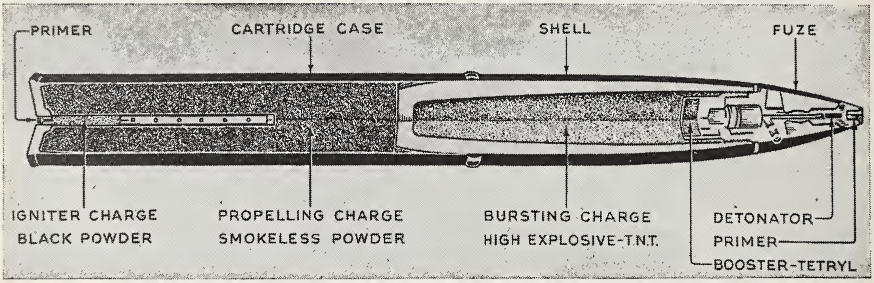


Fig. 24–8. A shell and cartridge case with high and low explosives.

The firing pin explodes the *primer*, a sensitive explosive called fulminate of mercury, in the base of the shell. This, in turn, explodes the smokeless powder, nitrocellulose, which is called the *propellant*. The hot gases from the burning powder push the projectile out of the muzzle of the gun at high speed.

The projectile, or shell, is loaded with a high explosive, usually TNT, which is not very sensitive to shock and can withstand the blow of being fired from a gun without exploding. When the shell hits the target, a primer in the nose of the shell is exploded with a force sufficient to explode the TNT, which bursts its steel case.

If dynamite or TNT were used as propellants, the speed of the explosion would burst the gun. Dynamite is more sensitive to shock than TNT; and if it were used as the high explosive, it would be exploded by the propellant before it reached the end of the barrel. In other words, dynamite is unsuitable either as a propellant or as a high explosive in firing a shell. In spite of these limitations it is an extremely useful explosive.

Dynamite. Although large quantities of explosives are used in war, about 95 percent are used for peaceful purposes. Dynamite is by far the most useful explosive; it is one of our greatest labor-saving devices. It is used for blasting coal, ores, and rock; for clearing farmland; and in the construction of tunnels, harbors, canals, dams, and highways. A few cents' worth of dynamite can blast four or five tons of solid rock for the construction of a highway. About 200,000 tons of dynamite are used annually in the United States upon construction projects.

Dynamite was invented by Alfred Nobel,

a Swedish chemist. It is made from nitroglycerine, a liquid high explosive which is dangerous to handle because it is exploded by only slight shocks. Nobel found that if nitroglycerine is absorbed by charcoal or sawdust it becomes much less sensitive to shock and therefore less dangerous to handle. This mixture is known as dynamite. Nobel made a fortune in his explosives, the greater part of which he left for the endowment of the Nobel prizes.

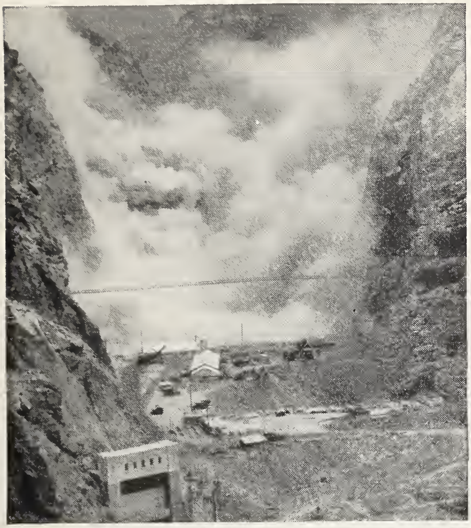

Courtesy U.S. Bureau of Reclamation

Fig. 24–9. Blasting away the canyon walls in constructing the Hoover Dam. More than 1,750 tons of dynamite were used in this project.

The Nobel Prizes. In his will Alfred Nobel wrote: "The interest accruing from the securities of my estate shall be awarded annually in prizes to those five persons who shall have contributed most materially to the benefit of mankind during the year immediately preceding . . . . . One . . . in the domain of Physics; one . . . in Chemistry; one . . . in Physiology or Medicine; one . . . in Literature . . . and, one to the person who shall have done most to promote the Fraternity of Nations and the Diminution of Standing Armies and the Formation of Peace Congresses."

The sum invested was nearly $8,000,000, and each annual prize amounts to almost $30,000. No other fund has ever been devoted to more idealistic purposes, and no other prizes have brought greater distinction to the winners.

Nobel believed that the destructive power of his explosives would advance civilization, reduce human drudgery, and, at the same time, lessen the risk of war. He wrote to a friend: "My factories may end war sooner than your peace conferences. The day when two army corps will be able to destroy each other in one second, all civilized nations will recoil from war in horror and disband their armies." This was written in 1892. It is interesting to note that within recent years similar hopes have been expressed for the atomic bomb.

Energy in Explosives. Strange as it may seem, the total energy in an explosive is usually not greater than that in a nonexplosive substance. Indeed, the energy in a pound of TNT or dynamite is much less than the energy in a pound of gasoline or coal. That is to say, a pound of coal or gasoline can do more work than a pound of TNT. An explosive effect is due to the *speed* of the reaction. A lump of coal may take half an hour to burn, so that, although it releases a great deal of heat, the energy is released too slowly to develop explosive effects. Nitroglycerine and dynamite, on the other hand, explode almost instantaneously. For example, a cartridge of dynamite five miles long would burn from end to end in less than one second. Even the explosion of gasoline and air is slow when compared with the explosion of dynamite or the burning of smokeless powder. Smokeless powder is not a suitable fuel for an internal-combustion engine because its rate of burning is too fast.

THINGS TO REMEMBER

The *kindling temperature* of a substance is the temperature to which it must be heated before it starts to burn.

Sir Humphry Davy invented the miner's safety lamp.

Spontaneous combustion is burning that takes place without the application of heat to start the reaction.

An *explosive force* is caused by the sudden expansion of the gaseous products by combustion in a confined space.

In an *internal-combustion* engine the explosion takes place inside a cylinder and the explosive force is used to do work.

Carbon monoxide, a poisonous gas, is a product of incomplete combustion.

Gunpowder is a mixture of saltpeter, charcoal, and sulfur.

A *low explosive,* such as gunpowder, burns more slowly than a *high explosive,* such as TNT.

Dynamite, invented by Alfred Nobel, is the most widely used explosive.

QUESTIONS

A

1. Who were: (*a*) Sir Humphry Davy; (*b*) Alfred Nobel?

Swedish Chemist

2. Explain the following terms: (*a*) kindling temperature; (*b*) spontaneous combustion.

3. A block and a sliver of wood are placed in a Bunsen flame for a moment. One burns and the other does not. How do you explain this?

4. Write word equations for the following reactions: (*a*) spontaneous combustion of coal; (*b*) spontaneous combustion of oil; (*c*) explosion of hydrogen and oxygen; (*d*) explosion of gasoline vapor.

5. What is an internal-combustion engine?

6. What is: (*a*) a high explosive; (*b*) a low explosive? Give an example of each.

B

7. "A fire can be extinguished if the burning substance is cooled below its kindling temperature." Describe an experiment you could perform to prove this statement.

8. Explain carefully how the Davy safety lamp prevents explosions in coal mines.

9. Explain why oily rags may suddenly burst into flame if they are left in a closed cupboard.

10. How do you account for the force that drives the piston down the cylinder of an internal-combustion engine?

11. (*a*) What is gunpowder?
(*b*) How is the oxygen supplied to gunpowder to enable it to burn?

12. How is gunpowder able to develop enough force to project cannon balls through space?

1 3 2

13. Compare nitroglycerine, TNT, and dynamite as to their sensitivity and speed of reaction.

14. Gasoline is poured into one small metal container and gunpowder into another. When the containers are full, they are closed by a screw cap. The two containers are then heated. What will probably happen? Why will it happen?

PROJECT

Reporting on Contributions to Science. Look up the Nobel prize winners in physics, chemistry, and medicine in the *World Almanac,* an encyclopedia, or in some other suitable reference book. Also read the article on the Nobel prizes in the *Scientific American,* December, 1949. List the winners for each of the above groups under the headings American, British, German, French, Other Countries, from 1902 to the present day. Examine the list.

Has any Canadian received the award? How many countries have shared the Nobel prizes? How does the awarding of the Nobel prizes contribute to the progress of scientific knowledge among nations?

Chapter 25

THE CONTROL OF FIRE

Fire under control is one of man's greatest benefactors; fire out of hand is his greatest enemy. Until relatively recent times man feared fire; now that he has learned to control it, fire has lost most of its terror. Yet the losses in life and property caused by fire are still staggering.

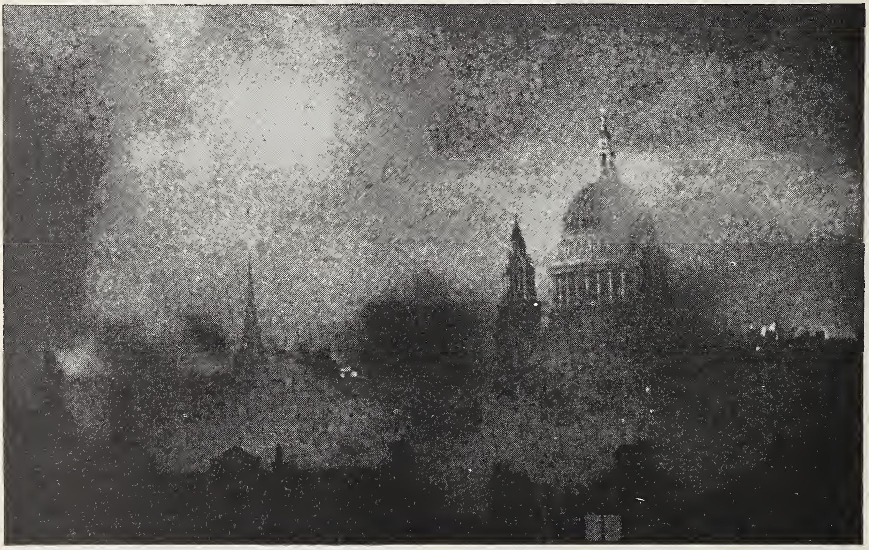
In the Middle Ages townspeople lived in wooden houses built so close together that a fire in one house endangered the whole community. It is not surprising, therefore, that the first attempt to control fire was by means of a curfew law, which required that all fires in houses be extinguished at a certain hour every night. (The word *curfew* comes from the French and means "cover the fire.") This law was enforced throughout Europe in the Middle Ages.

The early methods of controlling fires were very inefficient. Thus some fires caused such great destruction that they have become historical events. During the Middle Ages fires in large cities caused heavy losses of life, valuable property, and priceless works of art.

Famous Fires in History. Few cities have suffered as much as London. Of the many fires London has experienced, the Great Fire in the 17th century was the most disastrous. A severe plague of typhus had swept through the city, causing two-thirds of the inhabitants to flee in terror. A few months later the Great Fire destroyed more than three-quarters of the city, leaving 200,000 people homeless. Starting in a baker's shop, the fire was swept out of control by a strong wind and burned furiously for four days. Old London was an ideal place for such a conflagration; the houses were made of wood, they stood very close together, and, to make matters worse, their roofs were dressed with pitch and tar. The original St. Paul's Cathedral was among the famous buildings destroyed. Both the plague and the fire are discussed in Pepys' *Diary*.

Some fires have changed the course of history. The burning of Moscow is an outstanding example. In the early part of the 19th century Napoleon completely dominated Central Europe. When he triumphantly entered the city of Moscow, the Russians deliberately set fire to their city to prevent its being taken. A high wind fanned the flames, which soon got beyond control and destroyed the city. Since there was no shelter for the French armies from the approaching winter, Napoleon was forced to retreat. This was one of the greatest military disasters in history. It is described in Tolstoy's *War and Peace*. The wintry blizzards came early, and thousands of French soldiers were frozen as they slept. Napoleon had entered Russia with an army of 650,000 men; he returned to France with a disorganized mob of less than 10,000. Napoleon was defeated by fire and cold more thoroughly than he had defeated his opponents in battle. He never regained his military strength; the retreat led to his loss of the war, to his abdication, and finally to his exile.

In the United States, two of the most destructive fires were the Chicago fire in 1871 and the San Francisco fire in 1906. By 1870 Chicago had become the gateway to the developing Middle West and was one of the largest cities in the United States. It had grown at a remarkable rate to accommodate its rapidly expanding industries. There had been little time in which to erect brick and stone buildings. Most of the structures, even the sidewalks, were made of wood.



International News Photo

Fig. 25–1. Photograph taken during the night raid on London, December 29, 1940. St. Paul's Cathedral in the background miraculously escaped destruction.

During September, 1871, a dry wind blew steadily for three or four weeks. The moisture evaporated from the woodwork, leaving the buildings as dry as kindling. Early in October a fire broke out in the lumber district. Fanned by a strong wind, it soon got out of control. In a single night it destroyed the whole city of Chicago. More than 300 people lost their lives, 100,000 were made homeless, and at least 17,000 buildings were destroyed.

San Francisco has had seven disastrous fires. The worst fire occurred in 1906, immediately after a severe earthquake. The earthquake caused enormous property damage, breaking both gas and water mains. The fire was probably started by the ignition of escaping gas; it spread fast and furiously because there was a lack of water with which to fight it. The fire was finally checked by using dynamite to blow up buildings in its path. Many fine buildings were sacrificed in this way. Reducing them to rubble, however, choked the flames and at least a part of the city was saved. As in the Chicago fire, the toll of life was heavy and 28,000 buildings were destroyed.

In World War II, cities were destroyed by fires started by incendiary bombs. In 1940 the Germans tried to destroy London by fire. During one night more than 100,000 incendiary bombs were dropped, and when the fires were well started, high explosive bombs were dropped on the burning buildings to spread the flames. Water mains had been smashed. Fire-fighting was therefore extremely difficult and dangerous. Many historic buildings and churches were completely wrecked, and the financial losses could scarcely be calculated.

But London was not the only victim of fire raids. Before the end of the war, Tokyo, Berlin, and many other cities had suffered a fate worse than that of London. Thus modern warfare has introduced a new kind of incendiary terror, the deliberate destruction of cities by fire raids from the air. Let us now consider some of the modern methods of fighting fires.

Courtesy National Board of Fire Underwriters

Fig. 25–2. Fire fighting.

Three Methods of Extinguishing Fires. You may recall Lavoisier's statement that fire is the result of a chemical reaction between a combustible substance and oxygen. This statement gives the clue to the control of fire because, once the nature of the fire is understood, it can be controlled. Fires can be extinguished in three different ways: (1) *by removing the combustible material*, (2) *by cooling the substance below its kindling temperature*, and (3) *by excluding air from the burning substance.*

(1) *Removing Combustible Material.* This is the least important method because it is the most difficult. It is, however, usually the only way by which a forest fire can be controlled. A path in front of the fire is cleared of undergrowth and trees to prevent the fire from jumping the gap.

(2) *Cooling a Substance below Its Kindling Temperature.* This method is applied in the Davy safety lamp, where the wire gauze causes the cooling effect. Water is commonly used for cooling purposes. Not only does the water cool a substance below its kindling temperature, but wetting a substance makes it more difficult to burn.

Protection against fire has long been recognized as a community problem. The fire departments now organized in every town carry a great deal of equipment, including powerful pumps that throw water to a great height. Without an ample supply of water, a fire department is helpless. It was the lack of water that allowed the San Francisco fire to become so widespread and destructive. To prevent a repetition of this catastrophe, large storage tanks have been built underground in San Francisco to provide an adequate reservoir of water in case of emergency. Similar precautions have been taken in other cities.

Skyscrapers present another problem in fire protection. Even with the most powerful pumps it would be impossible to protect more than the lower floors of a very tall building. Tanks of water are therefore stored under the roof of a skyscraper so that in case of fire any part of the building may be flooded from this reservoir.

Department stores and large offices are usually protected against fire by a sprinkler system consisting of water pipes near the ceiling. The pipes have openings or jets sealed by an alloy with a low melting point. If a fire starts, the temperature soon rises high enough to melt the alloy, causing the water to flow out of the jets and quench the fire before it has progressed very far.

(3) *Excluding Air from a Burning Substance.* This is the most common method of extinguishing a fire. A blanket, a rug, or even a coat wrapped tightly around a person will at once extinguish the flames of burning clothing. For this reason a blanket is often kept in a laboratory as a fire precaution. Even a piece of paper will put out a fire if it prevents the air from getting to it, as is shown in the following experiment:

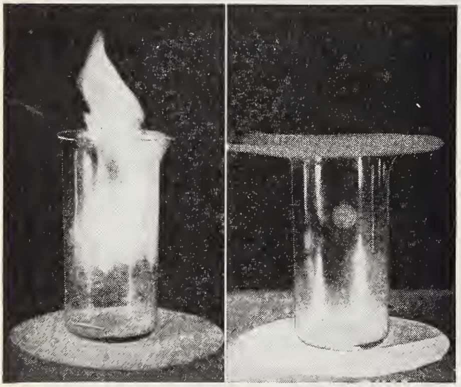


Fig. 25–3. On the left, gasoline is burning in a beaker. On the right, a filter paper has been placed on top of the beaker. This has prevented air from entering the beaker and the gasoline flame is at once extinguished.

Demonstration 25–1. To Extinguish a Gasoline Fire by Excluding Air.

Make a mixture of about 10 cc. of gasoline and 10 cc. of kerosene. Pour a little of the mixture into a one-liter beaker and ignite it by dropping a burning match into it. Cover the beaker with a large filter paper as shown in Fig. 25–3, and observe that the flame is at once extinguished.

Probably the most effective fire extinguisher, however, is carbon dioxide. We shall now examine some of the properties of carbon dioxide to see why it is an efficient extinguisher.

Carbon Dioxide. Carbon dioxide is about one and a half times as heavy as air. Its weight is an advantage in extinguishing a fire, because the gas will displace the air and thus smother the flame.

Demonstration 25–2. Carbon Dioxide Displaces Air.

Prepare some carbon dioxide by arranging the apparatus as shown in Fig. 25–4. Pour some dilute hydrochloric acid on pieces of marble in the generator. A chemical action takes place, producing carbon dioxide. To tell when the bottle is filled with the gas, hold a burning taper near the mouth of the bottle. If the taper is extinguished, the bottle is full of carbon dioxide.

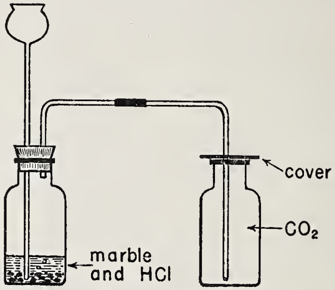


Fig. 25–4. Preparation of carbon dioxide.

Now balance a paper bag placed on the pan of a chemical balance or a triple-beam balance, and pour carbon dioxide into it as shown in Fig. 25–5.

Notice that carbon dioxide is so heavy it can be poured like water; it therefore sinks to the bottom of the bag, thereby displacing the lighter air. The balance soon registers a marked increase in weight.

If a burning match is plunged into carbon dioxide, it goes out instantly; the gas neither burns like hydrogen nor supports burning like oxygen. *Carbon dioxide cannot burn* because it is one of the products of combustion; it already has its maximum amount of oxygen and is unable to take up any more. It is this

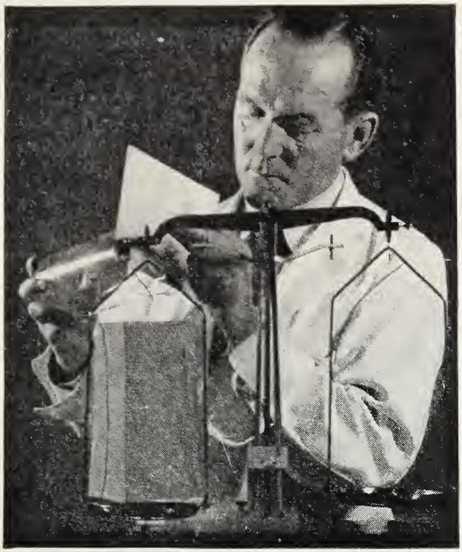


Fig. 25–5. Carbon dioxide is denser than air.

property, together with its heaviness,—that makes carbon dioxide an ideal substance for extinguishing fires.

Demonstration 25–3. Carbon Dioxide Extinguishes Candle Flames.

Arrange the apparatus as shown in Fig. 25–6, in which several small candles are waxed into the groove of a V-shaped glass gutter held together by Scotch tape. Fill two bottles with carbon dioxide and then light the candles. Pour the gas down the gutter and observe that the candles are extinguished, one by one, as the carbon dioxide reaches them.

Fire Extinguishers. Fire extinguishers are compulsory safety devices in factories, public buildings, schools, airplanes, and railroad trains. They should be conveniently placed in every house. Extinguishers vary in size and type, the most common being the soda-acid and foamite extinguishers. In both types carbon dioxide is made by chemical reactions.

The Soda-Acid Extinguisher. The essential substances in this extinguisher are baking soda and an acid, usually sulfuric acid. When hydrochloric or sulfuric acid is poured into a solution of baking soda, a brisk reaction takes place, producing carbon dioxide, as can be shown by the limewater test.

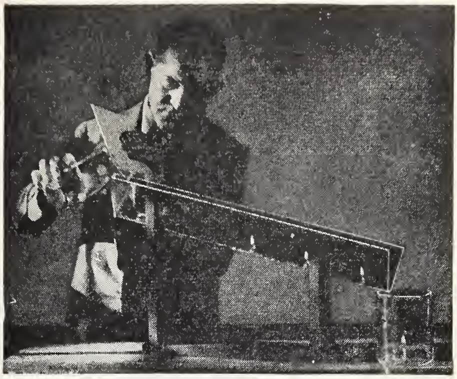


Fig. 25–6. Carbon dioxide is being poured down the trough and the two upper candles have already been extinguished.

The ordinary extinguisher is a copper vessel containing about two gallons of baking-soda solution. Near the top of the container is a metal basket that holds a bottle of concentrated sulfuric acid. When the extinguisher is inverted the baking-soda solution and the sulfuric acid mix; the solution and the carbon dioxide are expelled through a small flexible hose with considerable pressure, and are di-

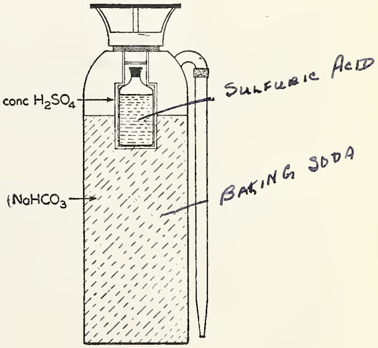


Fig. 25–7. A soda-acid fire extinguisher.

rected at the base of the fire. The pressure is great enough to force the solution through a distance of about 40 feet. The principle of the soda-acid extinguisher can be shown in the following experiment.

Demonstration 25–4. A Home-made Extinguisher.

Almost fill a small test tube with dilute hydrochloric acid. Place a two-hole stopper in the test tube. Fasten the test tube to the bottom of a heavy-walled bottle with rubber cement. Pour baking-soda solution into the bottle until it is about three-quarters full. Insert a small piece of glass tubing in the cap of the bottle, and attach a rubber tube and a glass jet to the glass tube. Screw the cap on the bottle. The arrangement is shown in Fig. 25–8.

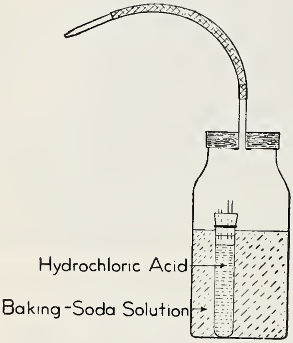


Fig. 25–8. A device to show the principle of the fire extinguisher.

Invert the bottle. The liquids mix, bubbles of carbon dioxide are formed, and the solution is forced out through the rubber tube. To test the extinguisher, put some excelsior on a metal tray, set fire to it, and play the stream on the fire.

The soda-acid extinguisher is most useful in dealing with fires of ordinary combustible materials like paper, wood, coal, or rubbish. It is unsuitable, however, for gasoline and oil fires, since the solution would sink below the gasoline and would probably cause the fire to spread. Nor is it suitable for controlling electrical fires, since concentrated sulfuric acid and sodium bicarbonate (baking-soda) yield solutions that are good conductors of electricity.

Gasoline fires, which spread rapidly, can be held in check by a thick foam of carbon dioxide bubbles, a substance usually called *foamite* or *firefoam.*

Foamite. When solutions of baking soda and alum are mixed, they react and form a foam of carbon dioxide bubbles that looks like whipped cream. A little licorice or glue added to the alum solution strengthens the bubbles so that the foam will remain intact for an hour or so. Such a foam will even stick to vertical surfaces and form a blanket over burning material.

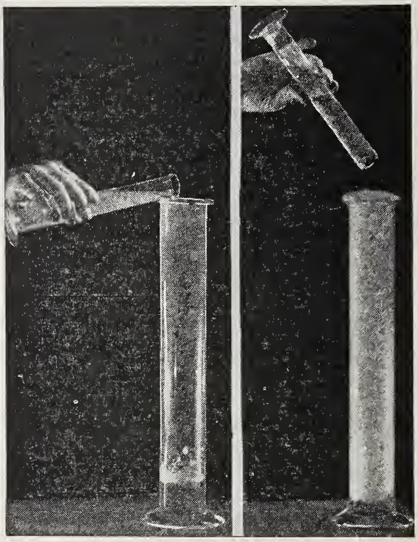


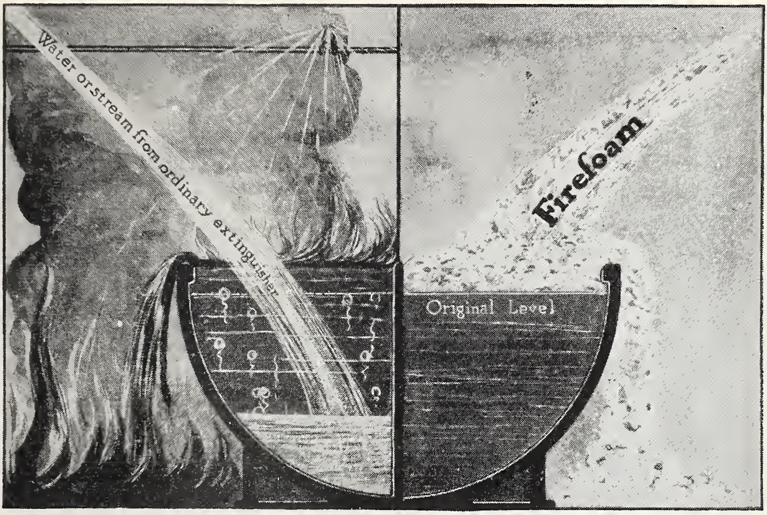
Fig. 25–9. Foamite. On the left, sodium bicarbonate solution is being poured into alum solution and the foam is beginning to form. On the right, foamite completely fills the cylinder.

Demonstration 25–5. Preparation of Foamite.

Make up an alum solution (80 grams per liter) and add enough glue to make the solution sticky.

Also make up a baking-soda solution (120 grams per liter).

Pour about 100 cc. of the alum solution into a tall glass cylinder (about 1-liter) and then add about 100 cc. of the baking-soda solution. The foam of carbon dioxide bubbles rises to the top of the cylinder, as shown in Fig. 25–9.


Water or stream from ordinary extinguisher
Firefoam
Original Level

Courtesy American-La France-Foamite Corp.

Fig. 25–10. On the left, water sinks in burning gasoline and causes the fire to spread, whereas, on the right, firefoam or foamite floats on the burning gasoline and extinguishes the flame.

In outward appearance the foam-type extinguisher resembles the soda-acid extinguisher. The alum solution and the soda solution are kept in separate containers and mix only when the extinguisher is inverted. A 2-gallon extinguisher produces about 20 gallons of foam. This type of extinguisher is in common use in industrial plants where inflammable liquids are used or produced.

Dry Carbon Dioxide. Unlike oxygen and hydrogen, carbon dioxide gas is easily liquefied by pressure. This property makes it convenient to store. Liquid carbon dioxide is used as a fire extinguisher. When the outlet valve of such an extinguisher is opened, the liquid carbon dioxide changes to gas instantly. The volume increases almost five hundred times, and the gas is thus forced out under considerable pressure. In escaping, the gas expands and cools to such an extent that some of it is converted into dry ice, which aids in extinguishing the fire.

Carbon dioxide gas is effective in extinguishing gasoline fires. Bottles of liquid carbon dioxide are placed, for example, near the motors of airplanes. Then if a fire should start in the motor compartment, the carbon dioxide would automatically be released from the bottles and flood the compartment.

Since carbon dioxide slowly mingles with the air, its smothering effect is not permanent. It should therefore not be used against substances that are likely to smolder, such as burning paper or wood, for after the carbon dioxide has diffused, these substances may burst into flame.

Carbon Tetrachloride. Carbon tetrachloride is the chief ingredient of liquids sold under various trade names. It forms a heavy noncombustible, somewhat poisonous vapor almost four times as heavy as air, making it even more efficient than carbon dioxide in extinguishing fires. Because it does not damage woodwork, draperies, and upholstery, it is often used as an extinguisher in homes. Only a little of the liquid is usually needed. The extinguishers are therefore quite small; they hold about a quart of the liquid. Because carbon tetrachloride vapor readily extinguishes oil and gasoline fires, it is usually carried in airplanes and railway coaches, and sometimes in automobiles. Carbon tetrachloride is also effective in combating electrical fires, since it does not conduct electricity.

At high temperatures carbon tetrachloride reacts with the oxygen of the air to form phosgene, a highly poisonous gas. Although the amount of phosgene formed in an ordinary fire is relatively harmless, users of this type extinguisher should be aware of the danger.

Demonstration 25–6. Carbon Tetrachloride as a Fire Extinguisher.

Roll up a large filter paper, ignite it, and then drop it into a tall one-liter beaker. Pour some carbon tetrachloride over the burning paper to extinguish the flame. Notice the heavy vapor of carbon tetrachloride in this beaker, which is made visible by the smoke particles.

Pour about 10 cc. of gasoline into another tall one-liter beaker. Ignite the gasoline and then pour carbon tetrachloride *vapor* over the gasoline flame. The flame is extinguished as soon as the vapor settles on it. Remember that the heated vapor can be poisonous; do not inhale it.

Courtesy U.S. Forest Service

Fig. 25–11. Disastrous forest fires may be started by carelessness.

Fire Losses in Canada. The destruction caused by fires throughout Canada has steadily increased, until it has now reached the annual figure of about $70,000,000. Since Canada is a heavily industrialized country, some serious fires in industrial plants may be unavoidable. But rigidly enforced fire laws safeguard industries so that they are not the chief cause of disastrous fires. Statistics show that 75 percent of these appalling fire losses are due to carelessness and could have been prevented. A list of all the causes of fire would be very long; we will give only a few of the major ones.

By far the greatest fire hazards are matches and cigarette stubs that are thrown away while still burning or smoldering. This item alone costs the nation $6,000,000 a year.

The burning of thousands of houses every year is due mainly to relatively few causes. First, the electric wiring may be defective so that a hot, bare wire may come in contact with woodwork. Or the house may have a defective chimney that allows red-hot sparks to pass through the wall and strike against a wooden floor. Or a careless person may forget to disconnect the electric iron so that eventually the ironing board is ignited. And finally, a thoughtless individual may throw a lighted match on a garage floor that is saturated with oil and gasoline.

The sparks from the smokestacks of locomotives also cause a considerable number of fires annually. Many forest fires are undoubtedly started by them. Campers who fail to extinguish their fires must also share the responsibility for this steady drain on the nation's forest wealth. Trees are important in many industries; paper, rayon, and many chemicals are made from wood. In a forest fire trees that have been growing from forty to a hundred years can be completely destroyed in a few hours.

We have already discussed the risks of spontaneous combustion. Wherever soft coal, sawdust, and grain are stored, precautions should be taken against fire.

Finally, we must not forget the effects of lightning, which may start fires in forests, oil wells, and in wooden houses unprotected by lightning conductors.

It is clear that fires are easily started. Combustible material and oxygen are all around us; all that is needed to start a fire is the spark to raise the material to its kindling temperature.

As citizens we have a grave responsibility in preventing fires. We should be aware at all times of the risks, and we should know how to act when we see the danger. Every Province protects its citizens in public places by fire laws. But fire laws are not enough to prevent disastrous fires unless we co-operate at all times. We can do a great deal to reduce this annual waste of $70,000,000 and the tragic loss of life that often occurs.

THINGS TO REMEMBER

Fires can be controlled in three ways: (1) by removing the combustible material, (2) by cooling the substance below its kindling temperature, and (3) by excluding air from the burning substance.

Carbon dioxide is a good fire extinguisher because it is heavier than air, and it cannot burn.

The common types of fire extinguishers are (1) soda-acid, (2) foamite, (3) dry carbon dioxide, and (4) carbon tetrachloride.

The ingredients in a soda-acid extinguisher are baking soda and sulfuric acid; in a foamite extinguisher they are baking soda and alum.

QUESTIONS

A

1. Name two fires that were important in history and two disastrous fires that occurred in the United States.

2. Give two reasons why carbon dioxide is a good fire extinguisher.

3. Describe a chemical test by which carbon dioxide can be detected.

4. What are the following: (*a*) limewater; (*b*) foamite?

5. Why is a soda-acid extinguisher unsuitable to fight a gasoline fire?

B

6. Why was the burning of Moscow an important turning point in history?

KEN E. RAINE

7. (*a*) Name the three different methods of extinguishing a fire.
(*b*) Describe an experiment that illustrates one of these methods.

8. Compare carbon dioxide with hydrogen and oxygen with respect to burning. Why do these substances have the properties you have listed?

9. Draw a diagram of the soda-acid extinguisher and explain how to operate it.

10. Write briefly on a destructive fire that occurred in: (*a*) Canada; (*b*) the United States.

11. State the similarities and the differences between the two common extinguishers that generate carbon dioxide by chemical action.

12. Write an essay on the causes of fires and fire prevention.

PROJECTS

1. *Visiting a Fire Department.* A visit to your local fire department is time well spent. Examine the equipment for fighting fires and ask the chief which safety devices should be installed in homes and public buildings. Also ask him about the precautions to be taken if a fire gets started in your home or in a hotel where you may be staying.
2. *Demonstrating the Use of Fire Extinguishers.* It may be possible to get the fire department to demonstrate the use of the various extinguishers.
3. *Using a Soda-Acid Extinguisher.* Burn some rubbish in an incinerator on wasteland near the school. Invert the extinguisher and direct the escaping stream onto the fire. Remember that the extinguisher should always be recharged as soon as it has been used.
4. *Using a Carbon Dioxide Extinguisher.* Pour a little gasoline into a metal tray. A galvanized iron tray about 2 feet by 1½ feet is convenient. Ignite the gasoline and then direct a stream of liquid carbon dioxide onto the fire. Notice that much of the carbon dioxide escapes as a cloud of dry ice.

This same experiment can be repeated using foamite and tetrachloride as the extinguishers.

Similarities
1. Both generate carbon dioxide
2. Contain baking soda
Both keep the substances separate until they are actually put to use.
Differences

Chapter 26

OIL AND ITS ORIGIN

Our most important fuels today are coal and oil. (*Oil* is here used interchangeably with *petroleum*; from crude oil or petroleum we get such products as gasoline, kerosene, lubricating oil, etc.) Outcrops of coal were first mined in the middle of the 13th century, but oil had been known for centuries before that time. In some places it seeped through the earth and formed pools of oil or sticky puddles of tar; in others, oil vapor and natural gas leaked through the rocks and caught fire, probably when struck by lightning. In Russia, near the Caspian Sea, such fires, fed by an underground pool of oil, burned for many centuries. The "Eternal Fires," as they were called, gave rise to a group of fire worshipers who built temples around them.

In Iraq, once called Mesopotamia, asphalt and tar were used as mortar to hold brick and stones together as early as 4000 B.C. It was also found that boats calked with tar were made waterproof and more seaworthy, so that man dared to take comparatively long journeys by sea. The practice of calking ships was developed particularly by the Phoenicians, who settled along the north Syrian coast about 2000 B.C. They became the merchants of the Mediterranean Sea, bartering goods with the Egyptians and the Greeks.

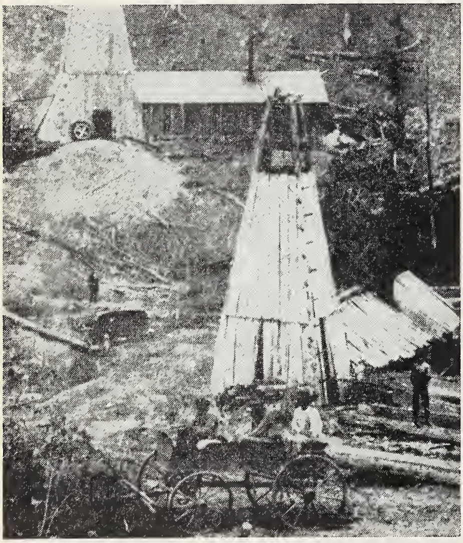
In ancient times burning tar was used in warfare—it was the parent of the modern flame-thrower. Castles and early cities were surrounded by walls to protect them against enemies, and one way of defending them was to pour burning oil on the attackers as they tried to scale the walls.

From earliest times oil was used as a medicine. The Egyptians and the American Indians rubbed it on their bodies to relieve aches and pains, and swallowed it to cure internal disorders.

Oil has long supplied light to mankind. At first, reeds were dipped into oil and used as torches. Later, oil was burned in lamps. The early American settlers used whale oil and also oil that seeped from the ground for their lamps, but the supply was not nearly enough for their everyday needs. When the seepage oil was used up, someone thought of digging into the earth to find the pools that had supplied these surface deposits.

This idea led to one of the world's largest industries. Many years elapsed, however, before men succeeded in bringing oil to the surface, for there were a number of engineering problems to be solved. In 1857, James M. Williams was producing and refining oil in Lambton County in Western Ontario. A Toronto newspaper "The Globe" reported in 1858 that Williams had drilled two wells, 100 and 150 feet deep. This marked the beginning of North America's petroleum history.

Williams was really interested in getting kerosene from the oil for use in lamps to replace the tallow candles and whale oil which were then in use. When the internal-combustion engine and the automobile were invented, the demand for oil increased enormously. The uses of petroleum products have continued to increase, until today petroleum is second only to coal as a source of energy. It furnishes power to airplanes, steamships, and many locomotives; it is used to heat thousands of factories, office buildings, hotels, and homes; as lubricating oil or grease it is used on all types of machinery. Indeed, without oil modern industry and transportation could not function.

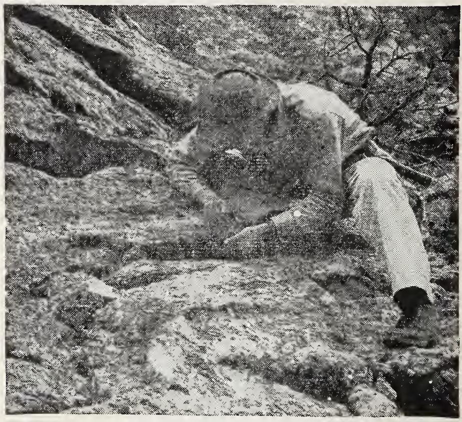


Courtesy Imperial Oil Limited

Fig. 26–1. Early oil well, Lambton County, Ontario, drilled in 1863.

The Location of Oil. To meet the enormous demand for oil, prospectors have made a world-wide search for it. Canada has over 700,000 square miles of prospective oil territory, most of which lies in a broad belt extending northwest from the U. S. border across the prairies and up to the Arctic Ocean. Alberta is the leading province in oil production, followed by Saskatchewan, the Northwest Territories, Ontario and New Brunswick. In spite of growing oil production in Canada the supply does not meet our needs, and geologists and engineers continue to search for new fields.

Where is oil found? So far not even the oil prospector has found a satisfactory answer to this question. In the early days the prospector, or wildcatter as he is usually called, had little evidence to help him select a site for his well. He examined the lay of the land and then made a guess, which often turned out to be wrong. The average cost of sinking a well is about $200,000, and no one was eager to gamble frequently with the stakes so high. Eventually it was realized that the search for oil is a scientific problem and that the geologist, the physicist, and the engineer all have important contributions to make before drilling can begin. But even today the methods of the scientists are far from certain; more than 50 percent of the wells are dry; that is, they do not yield oil.



Courtesy Standard Oil Co. (New Jersey)

Fig. 26–2. Field geologist examining the dip of the beds.

The Geologist at Work. The geologist wishes to discover the nature of the rock formations thousands of feet below the surface. The difficulty is, of course, that the only direct observations he can make are from outcrops on the surface or from *cores.* A core is obtained by a drilling bit with a hole in its center. Core samples may be 2 or 3 inches in diameter and from 4 to 20 feet long. By means of such cores the rock structure to a depth of several thousand feet can be examined.

Two conditions are essential for the formation of oil—a source bed and a trap. The *source bed* is a sedimentary rock, usually sandstone, that was once the floor of an ancient sea. Since petroleum is generally supposed to be caused by the decomposition of fish and plants that lived in this sea, it is not surprising that salt water is always found with oil.

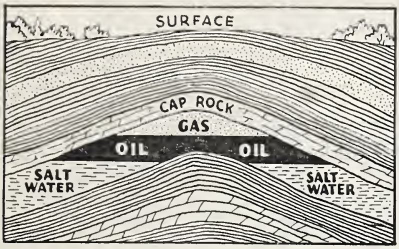


Fig. 26–3A. Impervious rock folded into an anticline forms a trap for oil.

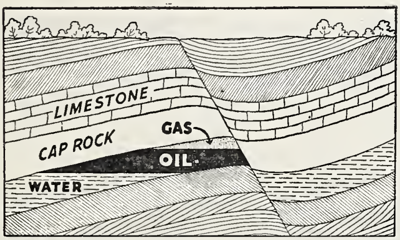
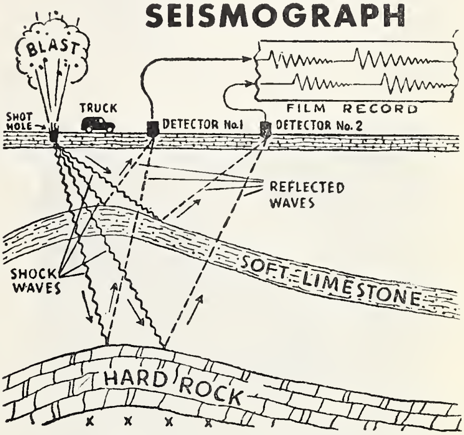


Fig. 26–3B. A fault forms a trap for oil.

The primary source of oil is microscopic plants called *diatoms*. As stated in Chapter 6, diatoms extract silica from sea water and build beautifully patterned shells. Inside these shells are the living plants which contain a droplet of oil. When the diatoms die, they sink to the sea floor, carrying the oil with them. Here they are compressed by additional deposits through geological ages, and crude oil results. If this oil-bearing rock is raised by an earth movement, it becomes a source of petroleum.

The *trap* is an obstruction against which the oil accumulates. It is due to peculiar rock formations such as folding or faults. To find geological oil traps the geologist examines the terrain, looking for outcrops of hard limestone, which is a common cap rock. To get more information, he may obtain a sample of the earth's crust by means of a core drill. As the drill grinds through the earth the core is packed into the pipe and can be lifted out. In examining the core the geologist learns a great deal about the composition and the age of the rocks below the surface. He then calls in the physicist, who obtains still more information by means of a seismograph.

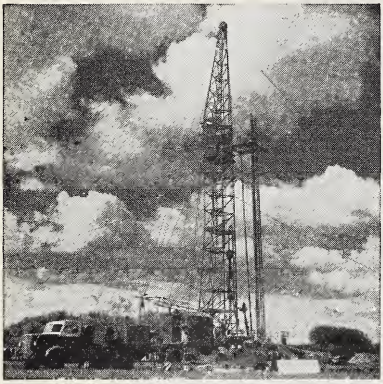


Courtesy Western Canada Petroleum Association

Fig. 26–4. How a seismograph records the underlying earth structure.

A *seismograph* is an instrument that records earthquakes. In searching for oil, a little earthquake is actually made by exploding dynamite buried in the ground. From the seismograph readings the physicist can determine whether conditions are favorable for an accumulation of oil. With all of this information the geologist may recommend that drilling begin.

Drilling for Oil. Drilling is a long and expensive operation. First a derrick, a steel structure from 150 to 200 feet tall, is erected for handling the drilling equipment. A bit is used to cut through rock in the same way as a carpenter's drill bores through wood. Samples of mud are constantly brought to the surface and examined for minerals and oil. The speed of drilling depends on the nature of the rock. Through hard rock the distance may be only a few feet a day; through soft rock it may be more than 100 feet a day. In deep wells, especially if considerable hard rock is encountered, drilling may take from nine to twelve months. When oil is struck, the drill is removed and the crude oil rushes to the surface.

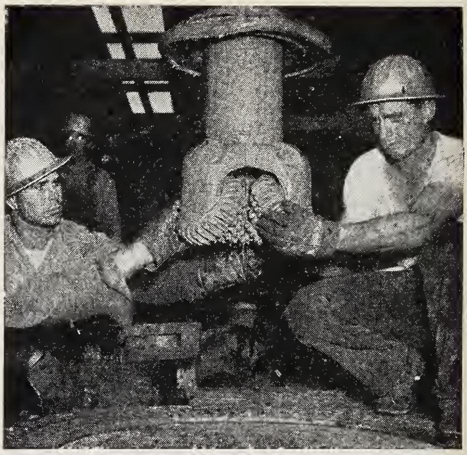


Courtesy Imperial Oil Limited

Fig. 26–5. Portable drilling rig.

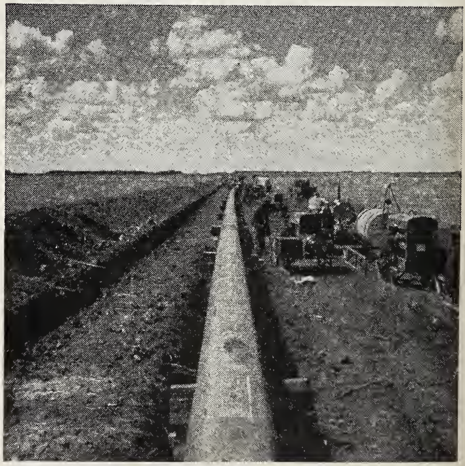
Transportation of Oil. From the wells oil is piped to storage tanks in the oil field. From there it is conducted by larger pipes to the refineries, which may be nearby or more than a thousand miles away. The oil is kept flowing in the lines by means of pumps.

There are almost 3,000 miles of oil pipelines in Canada. The longest of these is the 1,126-mile "Interprovincial" pipeline from Edmonton to Lake Superior. This line delivers over 4,000,000 gallons a day to Superior, Wisconsin. Here it is loaded on the largest freshwater tankers in the world and carried to refineries at Sarnia, Ontario. En route, the "Interprovincial" supplies refineries at Rosetown, Regina, Moose Jaw, Brandon and Win-



Courtesy Ohio Oil Co.

Fig. 26–6. A rotary bit used in drilling for oil.



Courtesy Imperial Oil Limited

Fig. 26–7. Constructing an oil pipeline.

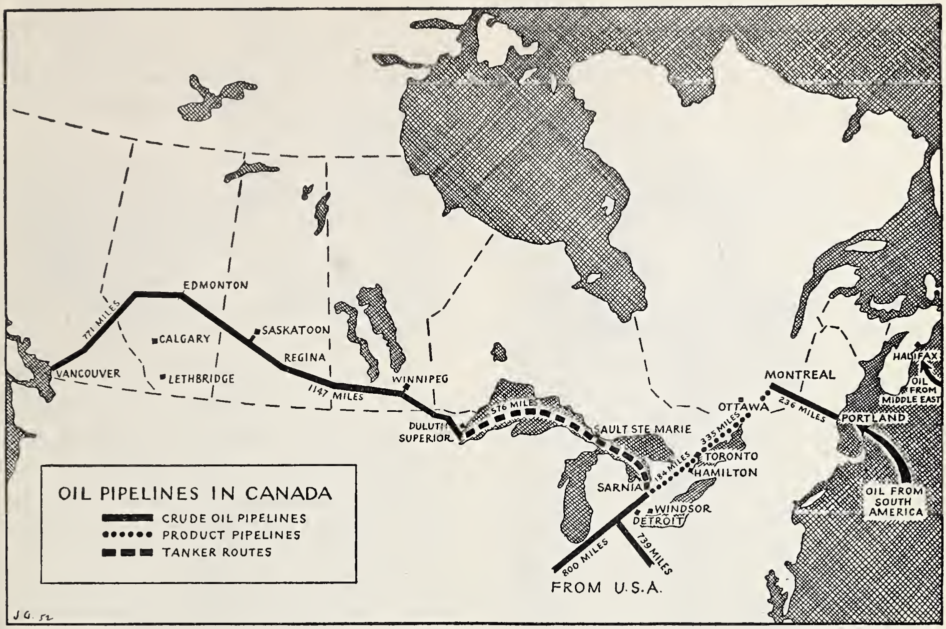


Fig. 26–8. Canada's growing pipeline system carries crude oil to distant refineries.

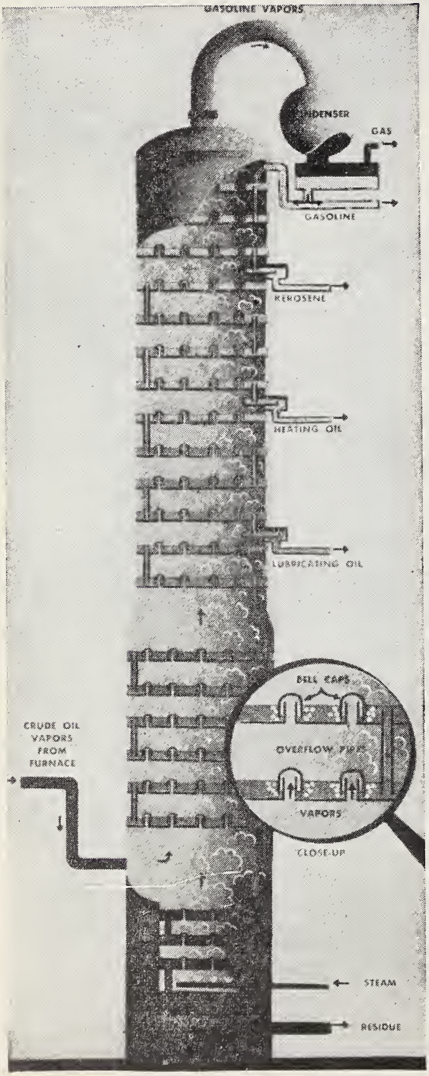
nipeg. Another pipeline carries oil from the Alberta fields across the Rocky Mountains to refineries in Vancouver.

Fractional Distillation. Crude oil is a mixture of several substances, including gasoline, kerosene, fuel oil, and lubricating oil. In the crude state oil is quite useless. Before it can be used to drive a car, heat a house, or lubricate machinery, it must be separated into useful *fractions*. The process of separating a mixture of liquids into fractions is called *fractional distillation*. This process is similar to ordinary distillation, except that a tall fractionating column (see Fig. 26–9) is placed between the boiler and the condenser.

In the refining process crude oil is first heated to a temperature of about 800° F.

Name of Fraction	*Condensation Temperature*	*Uses of Fraction*
1. Gasoline	About 150° F.	Fuel for automobiles and planes
2. Kerosene	About 300° F.	Illuminant; fuel for stoves and jet planes
3. Fuel oil	About 500° F.	Fuel for furnaces and Diesels
4. Lubricating oil	About 600° F.	Lubricants
5. Vaseline and paraffin wax	About 700° F.	Ointments and candles
6. Asphalt and tar	Residue	Road construction and roofing

The hot vapors enter the fractionating tower near the bottom. As they rise up the tower they become cooler and condense, collecting on trays at various levels. The highest boiling fraction condenses near the bottom, where the tower is hottest; and the lowest boiling fraction condenses near the top, where it is coolest. There are usually six outlets in the tower to carry off the fractions as shown in the table on page 237.



Courtesy Standard Oil Co. (New Jersey)

Fig. 26–9. A fractionating tower.

Gasoline. Gasoline is a low-boiling mixture of several hydrocarbons (compounds of hydrogen and carbon), including pentane, hexane, heptane, and octane. Since gasoline vaporizes easily, it is used in the internal-combustion engines of airplanes and automobiles. The chemical reaction that takes place is:

hexane + oxygen → carbon dioxide + water vapor

Because gasoline is highly inflammable, it is unsuitable for use as a household fuel.

Kerosene. Kerosene, like gasoline, is a mixture of several hydrocarbons. It has a high boiling point and is difficult to vaporize. Since it is not easily vaporized by a carburetor, it is not a suitable fuel for the ordinary internal-combustion engine. It is used, however, as a fuel in jet planes and also in oil stoves and lamps.

Fuel Oil. Fuel oil is another fraction of crude oil, or petroleum. It is more difficult to vaporize than kerosene; indeed, it can be burned only as a fine spray, and as such it is used in heating houses and in Diesel engines.

Lubricating Oil. Lubricating oil is more difficult to vaporize than fuel oil. This property is an advantage, however, because the oil would lose its effectiveness as a lubricant if it were evaporated by the heat of friction of the moving parts.

Asphalt. A viscous black substance collects at the bottom of the fractionating tower. This is asphalt and tar, which are used in road building and in the roofing of houses.

Cracking of Petroleum. The automobile and airplane industries depend almost entirely on gasoline. Even when aviation was in its infancy, the supply of *natural* gasoline (that

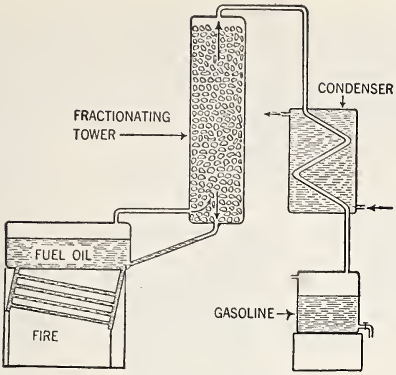


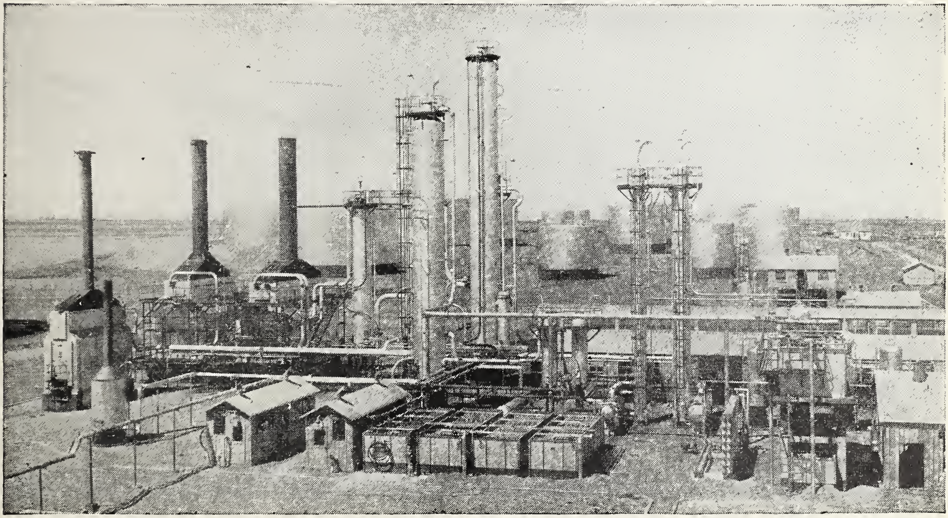
Fig. 26–10. Cracking of fuel oil.

is, gasoline obtained from crude oil by distillation) was so far below the demand that it became necessary to find a method of increasing it. Indeed, if scientists had not solved this problem, the development of the airplane would have been seriously hampered.

Chemists turned their attention to the kerosene fraction, since kerosene was then in least demand. They thought that if the long molecules of the kerosene fraction could be broken, or *cracked,* gasoline might be one of the products. In cracking, kerosene (or fuel oil) is subjected to a high temperature and a high pressure at the same time. The high pressure forces the molecules together and increases the number of collisions; the high temperature increases their speed and forces them apart. The molecules then break under this strain.

In the cracking process the vapors pass from the boiler to a fractionating tower, as shown in Fig. 26–10. Here the unbroken molecules of kerosene are condensed and returned to the boiler for further heating. The gasoline vapor passes through the tower and is condensed further along the line.

Cracking is a relatively recent development. Twenty-five years ago almost all gasoline was obtained by fractional distillation; today nearly 50 percent of the gasoline used in the United States is obtained by cracking.



Courtesy Universal Oil Products Co.

Fig. 26–11. A commercial cracking plant. Fractionating towers are in the center. On the left are oil heaters and in the background are tanks to store the gasoline.

Octane Rating. A knock in the engine of an automobile occurs when gasoline in the cylinders burns too rapidly and creates a sudden expansion of the gases, which results in a severe, hammerlike blow upon the piston. Knocking causes both a loss of power and an overheated engine, and thus prevents the engine from working smoothly and efficiently.

Gasolines vary from one well to another, some having higher antiknock values than others. Octane, for example, has a high antiknock value, whereas heptane has a low antiknock value. In other words, if octane is used, there is little knock in the engine; if heptane is used, there is a marked knock. The antiknock qualities of a gasoline are measured by a scale on which pure octane is rated as 100 and heptane is rated as zero. If the antiknock quality of a gasoline is equivalent to that of octane, the *octane number* of this gasoline is said to be 100. Similarly, a gasoline with an octane number of 80 behaves like a mixture of 80 percent octane and 20 percent heptane.

Ordinary gasoline has an octane number of about 75, high-test gasoline about 85, and aviation fuel at least 90. Some aviation fuels have numbers above 100, which means that their antiknock properties are better than those of pure octane.

The octane rating of a gasoline may be increased by the addition of some other liquid fuel. In Europe large quantities of benzene, obtained from coal, are used for this purpose. In the United States tetraethyl lead is usually added, and the gasoline is called *ethyl gasoline.* Tetraethyl lead is a highly poisonous liquid, but even one part of it in a thousand parts of gasoline greatly improves the octane rating of the fuel.

Synthetic Gasoline. In countries like England and Germany, where there is little oil but a great deal of coal, coal is converted into gasoline by a chemical process. It was found that *synthetic gasoline* could be made by heating powdered coal, which is mostly carbon, with hydrogen. Under the right conditions hydrogen atoms attach themselves to carbon atoms and form hydrocarbon molecules that can be used in internal-combustion engines. Gasoline made in this way is more expensive than distilled or cracked gasoline.

Synthetic gasoline is manufactured also in Canada. If the natural supply of oil becomes seriously depleted, the manufacture of synthetic gasoline may develop into an important industry. Our large deposits of lignite, a crude form of coal, would probably supply the needed gasoline for many centuries.

The World's Oil Supply. Although oil is found in many places, most of it is concentrated in four large regions, all near inland seas. Probably the most important oil region is the 1 eastern end of the Mediterranean Sea, including lands near the Caspian Sea, the Red Sea, the Black Sea, and the Persian Gulf. Rich oil deposits in this region are found in Iran, Iraq, Arabia, Romania, and southwestern Russia. The second most important oil region lies around the 2 Caribbean Sea and the Gulf of Mexico. It includes Mexico, Venezuela, Colombia, and the states of Texas and New Mexico. A third, less important, region is the 3. islands of Java and Sumatra in the East Indies and the Malay States and Burma. A fourth region, now being actively developed, is 4. western Canada. Several important oil fields have been discovered in Alberta, and discoveries have also been made in British Columbia, Saskatchewan and Manitoba. Since 1947 prairie oil reserves have increased nearly 30 times and it has now been proved that Canada possesses one of the world's major oil fields.

Oil Production in Canada. Canada has long been dependent on imported oil to supply her needs. However, oil production from the western fields is increasing at a rapid pace and the day may come when Canada will be self-sufficient in oil. In 1951 Canada's oil production was nearly 50,000,000 barrels (1 barrel = 35

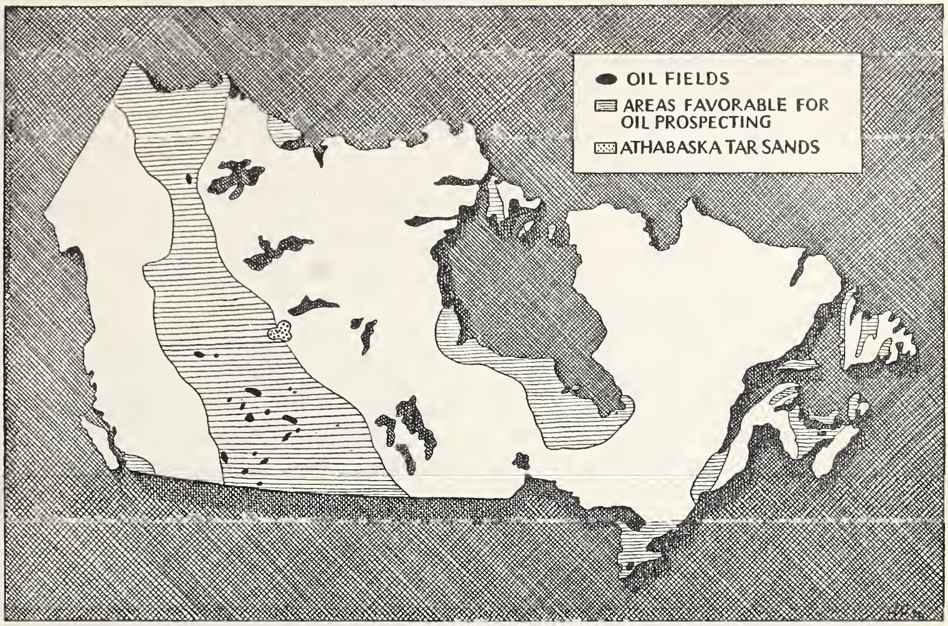


Fig. 26–12. Canada's chief centers of oil production are Alberta, Saskatchewan, the Northwest Territories, Ontario, and New Brunswick.

Imperial gallons) but she used nearly 150,000,000 barrels of oil products.

Besides the known oil fields Canada has a huge reserve in the Athabaska tar sands. This area consists of some 10,000 square miles of oil-bearing sand as much as 200 feet deep. So far no economical method of recovering the oil has been discovered but nearly all oil men believe that the problem will some day be solved. When that day arrives Canada will have a tremendously rich resource, perhaps a hundred billion barrels of oil—enough to supply the whole world for thirty years or more. The tar sands alone seem to be an answer to the fear that the world, if the present rate of consumption continues, will soon run short of oil.

THINGS TO REMEMBER

James M. Williams was producing and refining oil in 1857.

The *two essential geological conditions* for the formation of oil are a source bed and a trap.

A *source bed* is the floor of an ancient sea; a *trap* is an obstruction that encloses the oil.

Oil was probably formed by the decomposition of fish or diatoms.

Fractional distillation is a method of separating liquids with widely different boiling points.

Crude petroleum is refined to give the fractions (1) gasoline, (2) kerosene, (3) fuel oil, (4) lubricating oil, and (5) vaseline and paraffin wax.

Gasoline is a mixture of pentane, hexane, heptane, and octane.

Octane rating indicates the antiknock value of gasoline.

Cracking is a process whereby the long molecules of kerosene and fuel oil are broken into smaller molecules to form gasoline.

The *world's oil supply* is, for the most part, located in four regions: (1) the Eastern Mediterranean basin, (2) the Caribbean and Gulf of Mexico basin, (3) the East Indies basin, and (4) The North Polar basin.

The *Athabaska tar sands* hold one of the world's greatest oil reserves, an assurance against any future oil shortage.

QUESTIONS

A

1. (*a*) In what provinces do the major oil fields lie?
  (*b*) What is the estimated potential of the Athabaska tar sands?

2. What are diatoms?

3. What is the purpose of fractional distillation?

4. What is gasoline?

5. Why is fuel oil not generally used in the internal-combustion engine?

6. What is meant by cracking?

7. Name the four large regions in the world where oil is abundant.

B

8. Explain how oil deposits were formed from the oil in diatoms.

9. Explain the use of the fractionating tower in the cracking process.

10. What is meant by the octane rating of gasoline?

Chapter 27

COAL AND ITS ORIGIN

Modern civilization depends on the operation of millions of machines. Machines are driven by engines; engines, in turn, usually obtain their energy from water power or from a fuel such as coal, petroleum, or natural gas. Coal is the greatest source of energy—it supplies 75 percent of the energy used in the world. Coal heats more than half the buildings in the United States; it drives about 70 percent of the locomotives on railroads; it is used by thousands of ships; it provides more than 50 percent of the electric power sent over transmission lines. Indeed, the industrial might of the United States depends on coal.

Early Coal Mining in England. The use of coal in industry began in England early in the 18th century. Before that time the English used charcoal in the smelting of iron, but most of the forests that supplied the wood to make charcoal were soon destroyed. As a result the blast furnaces were transferred from the wooded regions of southern England to the north, where there were known deposits of coal. With the use of coal instead of charcoal, the output of iron increased rapidly, and England became the leading industrial nation of the world. Indeed, this was the beginning of the Industrial Revolution in England.

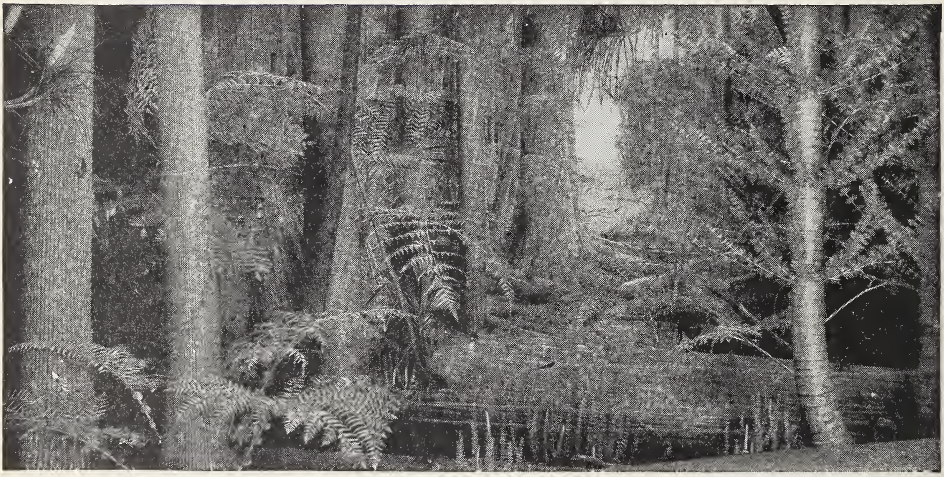
10 Coal mining presented new engineering problems. For the first time men had to work far below the earth's surface, where they were exposed to new dangers. The first problem was proper 1 *ventilation*, and it was many years before powerful fans were invented that could drive fresh air into all parts of a mine. Then there was the danger of 2 *explosion*. This danger, as we have learned, was greatly reduced when Sir Humphry Davy invented the safety lamp. Finally, there was danger from 3 *flooding*. During mining operations, water trapped within rock strata is often released, and enormous quantities of it must constantly be pumped out to prevent flooding of the mines. In some mines as much as 20 tons of water are pumped out for each ton of coal brought to the surface. In the early days of coal mining, men were often drowned while at work; sometimes a mine became unworkable because of flooding. A practical stationary steam engine that operated pumps and prevented flooding was made by James Watt. Watt's steam engine was as important a contribution to coal mining as was Davy's lamp, which was invented almost fifty years later.

Early Coal Mining in America. At the time of the Industrial Revolution in England the American colonists were blazing trails in the New World. They were occupied in fighting Indians as well as in making a living out of the soil. Their life was largely agricultural, and the vast forests supplied the wood for heating and cooking. It is doubtful whether they felt a need for coal.

Records show that the first coal-mining operation in America was started in Nova Scotia, by the French, when the famous Fortress of

Louisburg was being built in 1720. In 1750 an English company operated a coal mine near Richmond, Virginia, but at that time most of the coal used in the towns along the Atlantic coast came from England or Nova Scotia.

Coal and transportation have always been closely associated in the development of North America. The first railroads in America, built in Nova Scotia for horse-drawn cars, were for the transportation of coal from the mines to the wharfs. The development of railroads and steamships enabled the coal industry to expand rapidly. This step marked the beginning of the Industrial Revolution in North America.



Chicago Natural History Museum

Fig. 27–1. A Carboniferous forest, a collection of gigantic ferns, rushes, and club mosses.

The Origin of Coal. Coal was formed millions of years ago from plant materials that were crushed and decomposed under deposits of sand and mud. The conversion of vegetation to coal is a slow process, for it requires enormous pressures and fairly high temperatures applied through many centuries. It is one of the wonders of nature.

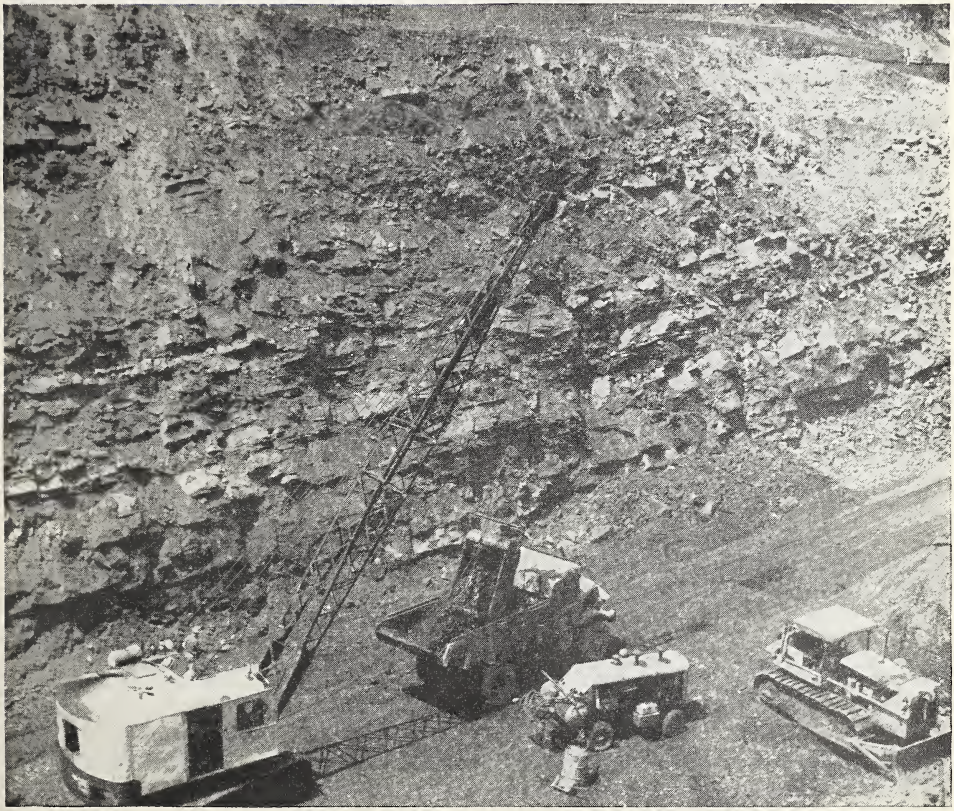
The world's greatest coal beds were formed during that part of the Paleozoic era known as the Carboniferous. This was a time when large areas of the earth's surface were near sea level. Over these areas great swamps had spread in which grew enormous quantities of plant life. As the land slowly subsided, the sea flooded the swamps, burying the plant material and depositing sand or mud over it. In the course of time the land was raised above sea level, and other vegetation grew in the sediment of mud and sand over the buried plant material. Still later the land again subsided, the sea again flooded the region, and mud and sand were again deposited. Subsequent high pressure and temperature slowly converted the vegetation into coal, the mud into shale or slate, and the sand into sandstone. For this reason coal is found in *beds,* or *seams,* which are separated from one another by layers of rock.

The coal beds vary in thickness from about one foot to as much as 50 feet. Every coal seam represents a long period of growth followed by a slow subsiding of the land. In some coal fields there are many seams one above another. In some places in West Virginia, for example, there are as many as thirty separate coal beds.

There are several varieties of coal, the most important of which are soft coal, or *bituminous coal*, and hard coal, or *anthracite*. The varieties of coal formed at the different stages of its development show a steady increase in the carbon content. Wood (about 50 percent carbon) changes to *peat* (about 60 percent carbon), which changes to *lignite* (about 70 percent carbon), which changes to *bituminous coal* (about 80 percent carbon), which changes to *anthracite* (about 90 percent carbon). A still later stage is the formation of *graphite* (about 100 percent carbon). Graphite is used in lead pencils.

Kinds of Coal. 1. *Peat* is the first stage in the conversion of vegetable matter to coal. It is found in bogs in many parts of the world, particularly in Ireland. It is dried in the sun and used as a fuel.

2. *Lignite* is a dark brown substance between peat and a true coal. It is not a good fuel because of its low carbon content. It is satisfactory for making synthetic gasoline, however, and in Europe it is used for this purpose. Enormous quantities of lignite, largely un-



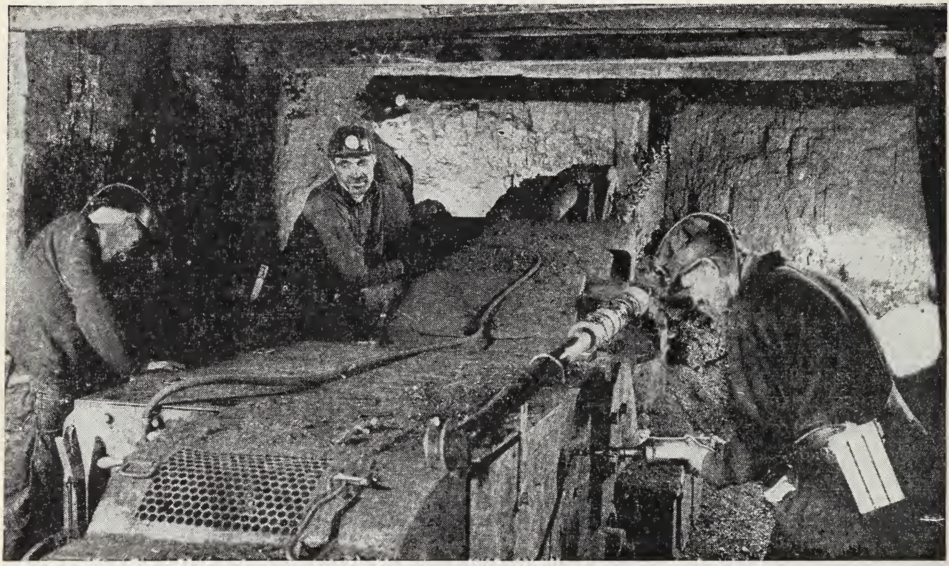
Courtesy Alberta Government

Fig. 27–2. Dragline loading coal in strip mining operation at Mannix Grassy Mountain, Blairmore, Alberta.

tapped, lie in Wyoming, North Dakota, Colorado, and Montana.

3. *Bituminous coal* is the most important coal. It burns easily and is widely used as a fuel to supply heat and power. When distilled, it gives off gases and tars that are used in many chemical industries.

4. *Anthracite* is much less important as an industrial fuel than bituminous coal, its uses being limited to heating and cooking. Almost all the important anthracite beds in the United States are in northeastern Pennsylvania.



Courtesy Bituminous Coal Institute

Fig. 27–3. A cutting machine making a vertical gash. Notice the horizontal gash that has already been cut at the top of the coal seam.

Coal Mining. When the coal beds lie near the surface, giant Diesel shovels strip off the covering of earth and expose the coal. The coal is then broken up by explosives, scooped up by shovels, and loaded on railway cars. This method, called *strip mining*, is common in Illinois and Indiana.

Most coal, however, is obtained from underground mines. The modern mine is carefully planned to give the maximum working space for the miners. First, a vertical shaft is sunk to the level of the coal seam. Then main streets are excavated leading to the coal beds, and cross streets are dug through the beds themselves. The streets are the traffic lanes and are arranged in much the same way as the streets of a city.

Excavations are then made at right angles to the streets and are enlarged to form the rooms in which the miners work. As coal is removed, the roof is supported by wooden or steel props to keep it from falling in.

Removing Coal. Coal is removed from the mines mostly by machines. First a cutting machine, with rapidly moving blades, makes a horizontal gash about 10 feet deep along the bottom of the coal seam. A horizontal gash is then made at the top of the seam, followed by a vertical gash through it. Since the cutting causes a great deal of coal dust, water is sprayed on the teeth of the machine to prevent explosions by spontaneous combustion. Holes are then drilled into the coal face and packed with an explosive, which is set off by electricity. A single explosion may blast from 10 to 20 tons of coal from the coal face. The coal is then loaded on cars and carried to a main underground assembly yard. The cars are hauled by an electric locomotive to the foot of the shaft and raised to the surface.

The main streets of the mine are usually illuminated by electric lights, but at the coal face the miner uses only the electric lamp and dry battery which he carries. The lamp is on his protective helmet, and the battery is attached to his back. The Davy lamp is still used in mines, but chiefly as a safety measure when testing for firedamp, as we learned in Chapter 24. When firedamp is present a blue cap appears on the flame, and from the size of the flame the percentage of methane can be calculated.

Safety Measures. The ever-present danger of gas explosions makes it necessary to enforce certain precautions against it. No open flame is permitted in the mine, smoking is prohibited, and men entering the mine are forbidden to carry matches. However, most accidents in coal mines are caused, not by explosions, but by falling roofs. Each miner is therefore required to wear a stiff helmet to protect him from a falling roof or a low ceiling.

Another hazard in coal mines is an explosion due to the coal dust created by cutting machines and by loading the coal on cars. Coal dust suspended in the air may be ignited by spontaneous combustion or by the explosion of a blasting charge. The ignition of the suspended dust may spread to the dust on the floor and walls, which in turn may explode. Disasters of this kind can be prevented if rock dust, such as powdered limestone, is scattered on the walls and floor of the mine. This procedure localizes an explosion. Rock dust thrown into the air by an explosion mixes with the coal dust. Being incombustible, the rock dust prevents the explosion from spreading throughout the mine.

Distillation of Coal. Coal is not only used as a fuel, but large quantities are also used to form coke, tar, and coal gas. If coal is heated in a closed vessel, it cannot burn because there is no oxygen. Instead it is baked, and it then decomposes into three substances: a solid residue called *coke*, a liquid called *tar*, and a gas called *coal gas*. The process by which these substances are obtained is known as *destructive distillation*, the third of the distillation processes. *Destructive distillation is the decomposition of a complex substance by heat and the condensation of some of the vapors.* For destructive distillation a substance must be heated out of contact with the air. Otherwise burning rather than decomposition would take place.

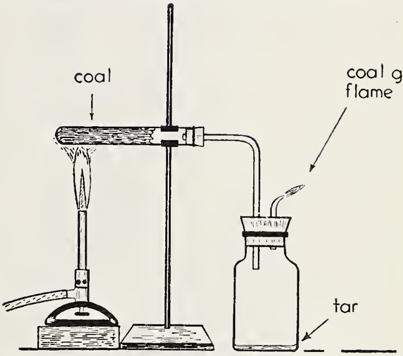


Fig. 27–4. Destructive distillation of coal.

Demonstration 27–1. Destructive Distillation of Coal.

Fill a pyrex test tube with soft coal. Fasten the tube to a stand, and connect it to a condensing bottle with a glass jet outlet as shown in Fig. 27–4. Heat the test tube strongly. Heavy vapors are evolved. Some of the vapors condense in the bottle to form a tar; others escape at the outlet and can be ignited. The residue in the test tube is coke.

Coke. Coke is a hard, smokeless fuel composed almost entirely of carbon. It is difficult to burn and, like charcoal, it glows without flame; yet it liberates a great deal of heat. It is used chiefly in the blast furnace to obtain iron from its ore (see Chapter 48).

Coal Tar. When coal was first distilled on a large scale, the important product was coal gas, which was wanted for heating and lighting. The coal tar was considered a useless by-product difficult to dispose of. If it was thrown on the land, it destroyed the vegetation; if it was dumped into rivers, it killed the fish.

Courtesy Parke, Davis and Co.

Fig. 27–5. William Perkin made the first coal-tar dye while experimenting, as a boy, in the attic of his home.

One of the first chemists to find a use for coal tar was an Englishman named William Perkin. About a century ago, when Perkin was only eighteen years old, he was working in a makeshift laboratory in his home trying to make the drug quinine from coal tar. He failed to make quinine, but he stumbled on a method of making a beautiful purple dye. This was the first artificial, or *synthetic,* dye. Chemists in many countries then eagerly turned to coal tar as a source of other synthetic substances.

Coal tar has proved one of the magic materials of the 20th century. Thousands of substances are now made from it. Tar is a mixture of many compounds, but only five are used on a large scale: benzene, toluene, phenol, naphthalene, and anthracene. From these five substances the chemist has synthesized explosives, drugs, dyes, perfumes, plastics, automobile fuel, photographic developers, and artificial rubber. Perkin's experiment has thus led to vast new industries and has probably influenced our modern civilization as much as any other single experiment in history.

Distribution of Coal. Coal is widely distributed over the earth. It is found in nearly every

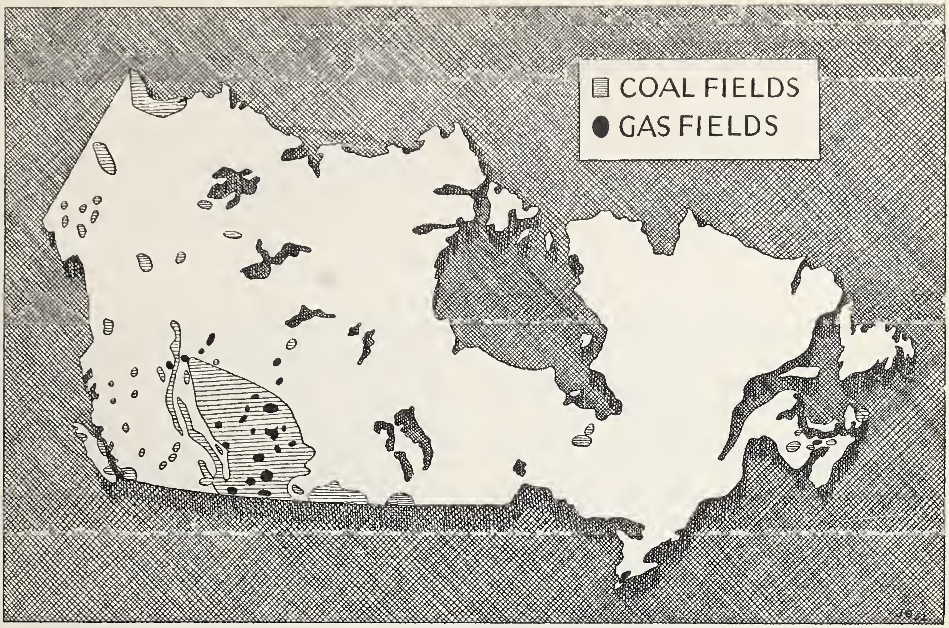


Fig. 27–6. Canada's coal and natural gas fields.

country in the world. The chief coal-producing countries are, in the order of their importance: (1) the United States, (2) Russia, (3) Great Britain, (4) Germany, and (5) France.

Canada has the second largest coal reserves in the world but only ranks twelfth in production. Because the location of the coal seams in the Maritimes and Western Canada are far removed from the industrial centers, over half the coal used in Canada is imported by Ontario and Quebec from nearby Pennsylvania.

About 15% of the world's coal supply is in Canada. Of the total resources, the Province of Alberta has the greatest portion, about 56%, followed by Saskatchewan and British Columbia. Ontario has a large deposit near James Bay, while Quebec has no known resources. Other important fields are in Nova Scotia, New Brunswick and Newfoundland. The map (Fig. 27–6) shows the extensive deposits of coal in Canada.

The annual coal output in Canada is almost 17,000,000 tons, and there are about 20,000 coal miners. Coal is mined in six provinces, Nova Scotia and Alberta far exceeding the others in output. At the present rate of mining the reserves are sufficient to last nearly 2,000 years.

THINGS TO REMEMBER

Coal is formed by the slow decomposition of plant material compressed by overlying strata.

Every *coal seam* represents a period of growth on land followed by a lowering of the land and its flooding by the sea.

During the conversion of vegetation to coal, the first change is to *peat*, the next to *lignite*, the next to *bituminous* coal, and the next to *anthracite*.

Spontaneous combustion caused by coal dust and *explosions* caused by methane are dangers in coal mines. Accidents are reduced by rock dust, good ventilation, and other safety measures.

Bituminous coal is the most valuable coal. It is used as a fuel and also in destructive distillation.

Destructive distillation is the decomposition of a complex substance by heat and the condensation of some of the vapors.

When *coal is distilled*, coke, tar, and coal gas are formed.

Coal tar contains five important compounds from which a vast number of substances have been synthesized.

About 15 percent of the world's coal is in Canada.

The largest coal field in Canada is in Alberta.

The greatest coal-producing provinces are Alberta and Nova Scotia.

QUESTIONS

A

1. Who were (*a*) James Watt; (*b*) William Perkin?

2. Explain the following terms: (*a*) lignite; (*b*) anthracite; (*c*) bituminous.

3. Define destructive distillation and give an example.

4. Name, in order, the five leading coal-producing countries.

5. Which three provinces contain the largest coal reserves in Canada?

B

6. Explain why the Industrial Revolution came later in North America than in England.

7. Write a short essay on the formation of coal.

8. (*a*) How is coal tar obtained? (*b*) Why is it an important substance in industry?

9. Discuss briefly the new engineering problems that presented themselves when coal mining began.

10. What is rock dust? How does it localize explosions in coal mines?

PROJECTS

1. *Collecting Carboniferous Fossils.* If possible visit a strip coal mine and ask the foreman for plant fossils from the coal seams and overlying strata. These are known as Carboniferous Fossils. Among them you will find fossil ferns and barks of ancient trees. Make a collection of them. Try, also, to get fossils of brachiopods from the limestones usually found above and below the coal seams.

   A visit to a museum is well worthwhile. Here you will learn the types and names of fossils to look for. A fossil collection started in this way can stimulate an interest in an extensive geological collection.

2. *Experimenting with the Destructive Distillation of Wood.* Wood, like coal, can be destructively distilled by heating it out of contact with the air. Arrange the apparatus as in Demonstration 27–1, filling the test tube with sawdust or wooden splinters. Heat the wood strongly. Notice that it is converted into charcoal. A gas, wood gas, escapes at the jet, and can be burned. Wood tar collects in the bottle, and also a watery layer containing acetic acid. Test the liquid with blue litmus paper to show that it is acid. At one time, the distillation of wood was an industrial method of making acetic acid.

Chapter 28

FUEL GASES

Gas, as a fuel, affects our daily living in many ways. It may be used to heat our houses, to cook our food, to supply hot water, and to run our refrigerator. In industry gas is used in steel furnaces; in making cement, glass, and china; in running electric generators; in refining sugar; and in manufacturing synthetic rubber.

Gas is replacing coal as a fuel for several reasons. It is easily controlled during burning, so the fire can be turned on or off at will; it is easily piped to any locality; it is free from smoke, ash, and dust; it requires much less labor and attention than do solid or liquid fuels.

It was many years, however, before people overcame the fear and superstition associated with inflammable gases. They had learned of explosions in coal mines and had heard of fires starting suddenly and burning, sometimes for years, in open places. They were content with the light supplied by candles and oil lamps. In the early part of the 19th century coal gas was first used for lighting the streets of some cities. This proved to be an experiment that won public confidence. When people realized that the danger of gas had been exaggerated, they were willing to install gas in their houses.

At first gas was used only for lighting. It was not thought of as a fuel. Then came Edison's electric lamp, which gave better light and was safer to use than gas. The result was a rapid decline in the use of gas, and the producers had to find a new use for their product. It was then that they stressed the advantages of gas over coal as a fuel. As a fuel, gas has grown steadily in importance, until it now has more than 20,000 industrial uses.

Fuel gases can be divided into two classes: natural gas and artificial, or manufactured, gas. Four-fifths of all the gas used in the United States is natural gas mined from underground deposits; the rest, which includes coal gas and water gas, is manufactured from coal.

Coal Gas. Coal gas is the oldest of the fuel gases. It was first prepared by distilling coal on a large scale toward the end of the 18th century. Soon the oil lamps and lanterns of Pall Mall, a famous London street, were replaced by coal-gas lamps; shortly afterward Westminster Bridge was also illuminated by gas.

In the United States, Baltimore was the first city to use coal gas for street lighting. Boston and New York soon followed. Some years later gas was used in public buildings, but not until about 1850 did wealthy citizens begin to light their houses with it.

Commercial Distillation of Coal. The commercial distillation of coal is an immense industry. It provides, besides coal gas, coke for the manufacture of steel and tar for synthetic chemicals. One-fifth of the coal mined in the United States is used in the distillation process. In this process coal is heated in a huge oven which consists of a battery of retorts, each retort holding about 10 tons of coal. The retort is heated strongly for 17 or 18 hours by the flames of a fuel gas and air. The vapors and gases pass out through an opening at the top, and only coke remains in the retort. After the heating, the red-hot coke is taken out and sprayed with water to keep it from burning away.

The heavy tar and oil vapors condense and are drained into a large tank. The vapors and gases are piped to a by-product plant, where they yield tar, light oil, ammonia, and gas. The light oil is used to improve the antiknock value and to increase the octane rating of gasoline. The tar is used in the synthetic chemical industry. The ammonia gas is used to make an important fertilizer. The remaining gas, which is coal gas, is then forced up steel towers called *scrubbers*. In one scrubber, *wash oil* is sprayed in at the top, and in the other, water is sprayed in. The wash oil removes the last traces of tar from the gas, and the water removes traces of ammonia and other impurities. The gas is now ready to be used as a fuel. Some of it is used to heat the oven for coal distillation, and the rest is piped to city gas mains, where it is stored for domestic and industrial uses.

Coal gas is a mixture of gases, the chief of which are hydrogen (about 50 percent), methane (about 35 percent), and carbon monoxide (about 5 percent).

Coal gas is one of the richest of the fuel gases. Its heat value is about 900 B.T.U. per cubic foot, far above the state legal requirement, which is usually about 530 B.T.U. per cubic foot. It is expensive to make, however, and it can compete with a cheaper fuel gas, like water gas, only because it is a by-product in the more important preparations of coke and tar.

Water Gas. Water gas is a mixture of about 50 percent hydrogen and 45 percent carbon monoxide. To manufacture this gas, a blast of hot air is forced through the coke, causing the following reaction:

carbon + oxygen → carbon dioxide + heat

or $$C + O_2 \rightarrow CO_2 + \text{heat}$$

The carbon dioxide is, of course, useless as a fuel gas and is not collected for this purpose. The heat of the reaction, however, soon makes the coke white-hot, an essential condition before the second operation can begin. After two or three minutes the air blast is shut off and steam is forced through the coke, causing the following reaction:

carbon + steam → carbon monoxide + hydrogen − heat

or $$C + H_2O \rightarrow CO + H_2 - \text{heat}$$

The mixture of carbon monoxide and hydrogen that is collected is water gas. In this reaction, however, heat is taken *in*, not given *out*, as shown by the minus sign in the equation. In other words, the temperature falls and, after two or three minutes, carbon monoxide is no longer produced. At this point the steam is shut off, and the air blast is turned on again until the coke is white-hot. These alternations of air and steam are necessary to the preparation of water gas.

Enriching Water Gas. When water gas is burned as a fuel, the reaction in the flame is

carbon monoxide + hydrogen + oxygen → carbon dioxide + water vapor + heat

or $$CO + H_2 + O_2 \rightarrow CO_2 + H_2O + \text{heat}$$

Unfortunately, the heat value of water gas is only about 300 B.T.U. per cubic foot, which is far below the standards set by the states. To raise its heat value, the gas must therefore be enriched by other substances. In the enriching process hot water gas is passed into a chamber called a *carburetor*, which contains broken brick. Oil is sprayed on the hot brick and the compounds in the oil are cracked into simpler compounds, including methane and ethane. The methane and ethane are then swept along with the water gas. This enriched gas is called *carbureted* water gas. Its composition is, roughly, hydrogen 40 percent, carbon monoxide 35 percent, methane and ethane 20 percent, other gases 5 percent. The heat value of methane and ethane is much higher than that of hydrogen and carbon monoxide; and, as a result, carbureted water gas has a heat value of about 550 B.T.U. per cubic foot.

Carbureted water gas is used extensively in industry. The plant for making it costs much less to build than the by-product coke ovens; and the starting materials — air, coke, and water—are inexpensive and abundant. One of the first essentials for a successful chemical industry is a cheap and abundant supply of raw materials.

Carbon Monoxide. It should be noted that both coal gas and water gas contain the poisonous gas carbon monoxide. Coal gas is from 5 to 7 percent carbon monoxide, and water gas from 35 to 40 percent. Since these gases are common fuels in our homes, precautions must be taken to prevent leaks at the gascocks.

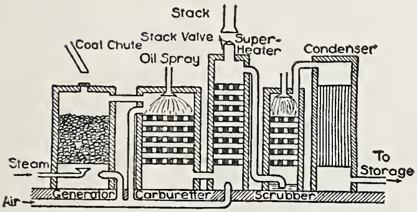


Fig. 28–1. Manufacture of water gas.

Carbon monoxide is the most poisonous of the common gases. Its poisonous nature is due to the fact that it readily combines with hemoglobin, the red coloring matter in blood. One of the vital functions of the blood is to carry oxygen from the lungs to the other parts of the body. Actually the oxygen combines with hemoglobin to form a compound. The compound is carried to the tissues, where the oxygen is released for oxidation purposes. Carbon monoxide is 300 times as soluble in blood as is oxygen. It therefore excludes so much oxygen from the bloodstream that not enough remains to support life. Even small amounts of carbon monoxide are very dangerous, and a concentration as low as one percent may cause death in a few minutes. Carbon monoxide is a treacherous poison, since it has no odor to reveal its presence.

3. **Natural Gas.** Natural gas is always present in oil fields. Indeed, it is the pressure exerted by natural gas that forces the oil to the surface. The gas is formed also in regions where there is little or no oil. In fact, at least 60 percent of our natural gas is obtained from gas wells, not from oil wells.

Drilling for *dry gas* is the same process as drilling for oil; that is, a derrick is erected, a well is sunk, and when the gas sand is tapped, the gas rushes up the pipes with a roar. The flow of the gas is controlled by valves, and as the gas is removed the internal pressure is diminished until eventually no more gas comes to the surface.

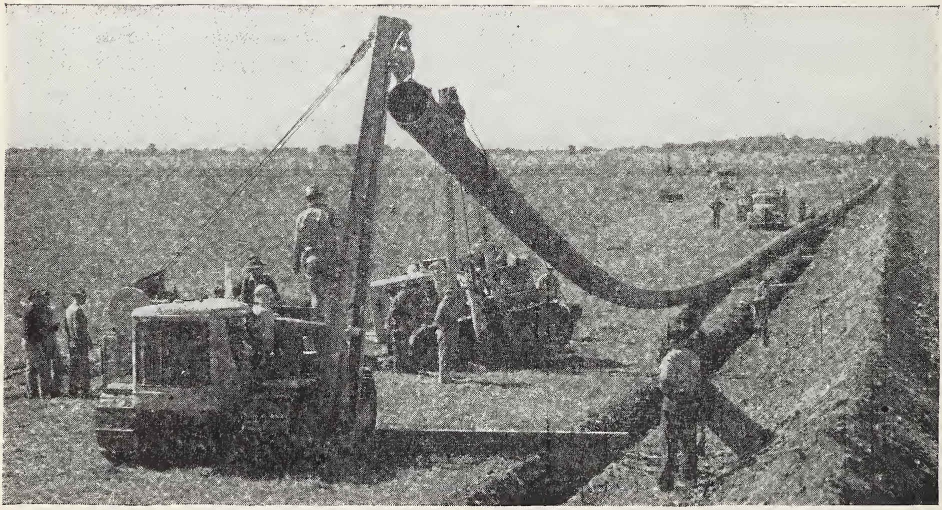
Gas from oil wells is highly charged with gasoline and other oils; it is called *wet gas*. The gasoline is separated from the natural gas by passing the mixture through vertical cylinders in which the gasoline condenses. Large quantities of *casinghead gasoline*, as it is called, obtained in this way add to the supplies of gasoline obtained from distillation and cracking.

Natural Gas as a Fuel. In the early days of oil mining, natural gas was regarded as a dangerous nuisance that sometimes caused explosions and fires. The oilmen led it away from the well to a safe distance and burned it. Enormous quantities of fuel gas were wasted in this way.

The use of natural gas in industry began over a century ago, when a workman struck natural gas while drilling a salt well in Butler County, Pennsylvania. He used the burning gas to evaporate the brine he pumped out of the well. This crude method of manufacturing salt was the beginning of a mighty industry. Men soon realized the possibilities of the gas. First it was used as a fuel in the oil fields to provide steam for the drilling and pumping machinery, and many years later it was piped to Pittsburgh for use in the iron foundries, rolling mills, and other industries. Today 10 percent of the nation's energy comes from natural gas.

Natural gas is a mixture of about 85 percent methane, 10 percent ethane, plus other hydrocarbons. It burns with a hot blue flame, and is the cleanest and most efficient of all fuel gases. Its heat value is more than 1000 B.T.U. per cubic foot, considerably higher than that of coal gas or water gas. One cubic foot of the gas will bake a pie; 60 cubic feet of it will bake 100 pounds of bread.

Natural Gas in Canada. Natural gas is found in British Columbia, Alberta, Saskatchewan, Ontario, New Brunswick and Nova Scotia. Ontario has made use of natural gas for many years, and an extensive network of pipelines exists throughout southwestern Ontario. Alberta and Saskatchewan have pipelines that serve communities close to the gas fields. In the United States natural gas is carried to industrial centers through pipelines thousands of miles long. This vast network extends about 200,000 miles—enough to circle the earth at the equator about eight times. Western Canada, particularly Alberta, is now discovering tremendous gas reserves, and a pipeline carries Alberta natural gas to Montana in the United States. This pipeline is probably the forerunner of a Canadian network that will supply our industrial centers.



Courtesy Caterpillar Tractor Co.

Fig. 28–2. Laying a natural-gas pipeline.

Synthetic Gasoline. Thus far we have considered natural gas only as a fuel. Natural gas has other important uses. For example, it can be converted into gasoline and carbon black. These manufactures are major industries. In Texas and Kansas gasoline is manufactured from natural gas by mixing the gas with oxygen and burning the mixture. The amount of oxygen used, however, is not sufficient for complete combustion, so that car-

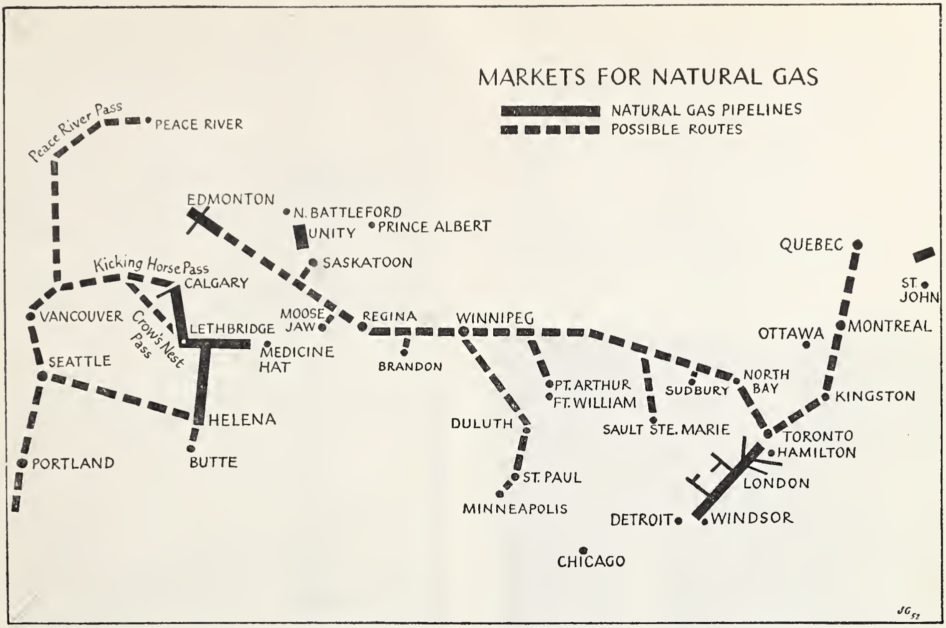
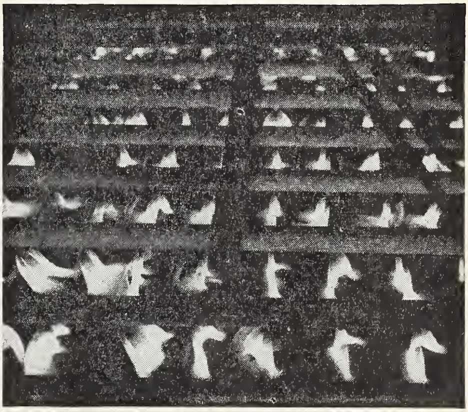


Fig. 28–3. Present and proposed underground pipelines to supply industrial centers with natural gas.

bon monoxide and hydrogen, not carbon dioxide and water, are formed. This is water gas. The water gas is then heated in the presence of iron, which acts as a catalyst, and gasoline is formed.

It is possible to convert coal into gasoline in the same way. First the coal is heated with hot steam to make water gas, and then the water gas is converted into gasoline. The conversion of natural gas and coal into gasoline and Diesel oil are two methods by which the natural supplies of oil can be conserved.

Carbon Black. The manufacture of carbon black is a fairly recent industry that has sprung up in the gas fields of Texas and Oklahoma. Carbon black, which is nothing more than soot that collects on the bottom of a teakettle, is made by the incomplete combustion of natural gas. In this process thousands of burners are placed underneath some iron beams. The luminous flames of the burning gas deposit carbon black on the beams, which move continuously. In moving they rub against scrapers that knock the carbon black into hoppers. In one recent year about three-



Courtesy Standard Oil Co. (New Jersey)

Fig. 28–4. In making carbon black, gas flames lick against an overhead bar and deposit soot upon it.

quarters of a million tons of it were made in this way.

Why is there a large demand for carbon black? Carbon black is used in the manufacture of many articles, including phonograph records, fountain pens, black leather, and paints and enamels used on kitchen ranges. But its more important uses are in the manufacture of printer's ink and rubber goods. All the blackest inks used in the printing of books, magazines, and newspapers are made from carbon black. This use alone makes carbon black indispensable.

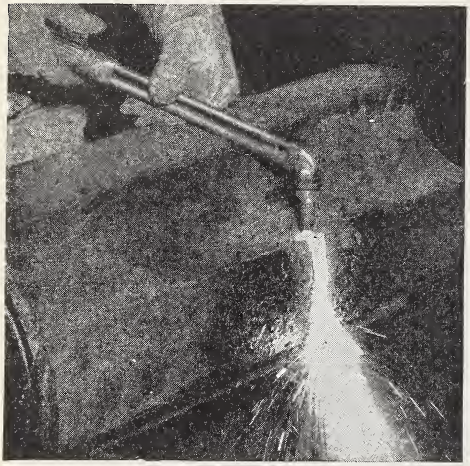

Courtesy Linde Air Products Co.

Fig. 28–5. An acetylene torch cutting through steel.

More than 90 percent of all the carbon black manufactured is sold to the rubber industry. The carbon black packs tight and makes rubber better able to withstand abrasion and heat. Thus it greatly increases the durability of rubber tires. Thirty years ago a flat tire was a common occurrence; fast driving would cause a blowout and tires rarely lasted for more than five thousand miles. The long life of the modern automobile tire is due in large measure to carbon black, which may constitute as much as 25 percent of its weight.

Acetylene. A discussion of fuel gases would be incomplete without some mention of the oxyacetylene flame. To make the flame, oxygen and acetylene from separate cylinders are mixed in a blowpipe and burned at the tip. Fig. 28–5 shows an oxyacetylene blowpipe in use. Acetylene is a hydrocarbon. The products of combustion are therefore carbon dioxide and water vapor. The heat released in this reaction causes one of the highest temperatures that can be produced by chemical means, 3000° to 3500° C.

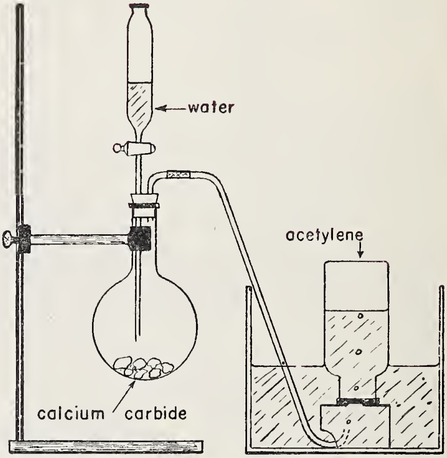


Fig. 28–6. Preparation of acetylene.

Because the temperature is well above the melting points of all the common metals, the flame is used for welding and cutting metals. If the flame is directed against a steel plate, for example, it melts the steel in its path. If more oxygen is then admitted to the flame, the superheated oxygen ignites the molten steel, causing it to burn as a shower of sparks. In this way it is possible to cut through a steel slab several feet thick.

The oxyacetylene torch cuts almost as well under water as in air. A torch of this kind was used in the underwater salvage work on the battleships disabled by the Japanese at

Pearl Harbor in World War II. In some cases, projecting metal pieces had to be cut away; in others, metal plates had to be welded over holes before water could be pumped out of the ship.

Acetylene gas can easily be made in the laboratory with calcium carbide and water. The reaction is vigorous, however, and the water must be added slowly.

Demonstration 28–1. Preparation of Acetylene.

Place some lumps of calcium carbide in a flask and arrange the apparatus as shown in Fig. 28–6. Water from the funnel is released slowly, drop by drop. As it strikes the calcium carbide, a vigorous reaction takes place and acetylene is evolved. Collect two bottles of acetylene by displacing water.

Because the first bottle contains most of the air from the flask, the gas in it may not be suitable for burning. Place a glass cover over the second bottle of acetylene and set the bottle upright on the table. Remove the cover and place a lighted taper near the mouth of the bottle. The acetylene burns quietly, with a sooty flame.

What causes the soot? The soot is free carbon that is formed because there is not enough oxygen to combine with it. Acetylene is rich in carbon—about 92 percent by weight is carbon. The liberation of free carbon in the acetylene flame is prevented by leading oxygen from a tank into it. In this way all the carbon is burned to carbon dioxide and the heat of reaction makes the flame exceedingly hot.

THINGS TO REMEMBER

Coal gas is a mixture containing 50 percent hydrogen, 35 percent methane, 5 percent carbon monoxide; *carbureted water gas* is a mixture containing 40 percent hydrogen, 35 percent carbon monoxide, 10 percent methane, 10 percent other hydrocarbons; *natural gas* is a mixture containing 85 percent methane, 10 percent ethane.

The legal heat requirement for a fuel gas is about 530 B.T.U. per cubic foot. The *heat value* of (1) *coal gas* is about 900 B.T.U. per cubic foot, (2) *water gas* about 300 B.T.U. per cubic foot, (3) *carbureted water gas* about 550 B.T.U. per cubic foot, (4) *natural gas* about 1100 B.T.U. per cubic foot.

Coal gas is manufactured in a coke oven by the destructive distillation of coal.

Water gas is manufactured by passing hot air through white-hot coke. It is enriched by methane, ethane, and other hydrocarbons.

1000 BTU. per cu. ft.

Natural gas is one of the richest fuel gases. It is found in six provinces, but most abundantly in Alberta, Saskatchewan and British Columbia.

Carbon monoxide is a constituent of coal gas and water gas. It is exceedingly poisonous.

Carbon black, obtained from natural gas, is used in the manufacture of printer's ink and rubber tires.

The temperature of the *oxyacetylene flame* is almost 3500° C. It is used for cutting and welding metals.

QUESTIONS

A

1. Name the three common fuel gases.

2. What is the state legal requirement concerning fuel gases? What does it mean?

3. Name a liquid, a solid, and a gas obtained from the distillation of coal.

4. Name 3 provinces that produce natural gas.

5. State two important uses of natural gas, apart from its use as a fuel.

6. What is carbon black? Name its two most important uses.

B

7. Describe the composition of coal gas.

8. (*a*) What is the difference between water gas and carbureted water gas?
(*b*) Why is water gas enriched?

9. Explain how and why carbon monoxide is poisonous.

10. (*a*) What is the heat value of natural gas?
(*b*) What does it mean?
(*c*) Why is heat released when natural gas is burned?

PROJECTS

1. *Visiting a Gas Plant.* Visit a water-gas plant. Notice the furnace for making the steam, and the steampipe from the furnace to the generator which contains coal or coke. Notice also the carburetor, where the water gas is enriched, and the arrangement for storing the gas under pressure before it is piped to the town.
2. *Observing Oxyacetylene Welding and Cutting.* Visit a shop where an oxyacetylene flame is being used. Notice the tanks of oxygen and acetylene to which the blowtorch is connected, also the small white oxyacetylene flame and the shower of sparks when the flame strikes the steel. Why does the operator cover his hands with asbestos gloves and his eyes with dark glasses?

Chapter 29

THE CARBON DIOXIDE CYCLE

Whenever burning takes place carbon dioxide is formed. As a result of the combustion of such fuels as coal, gasoline, and natural gas, millions of tons of carbon dioxide are sent into the air daily. Combustion is not the only process, however, that increases the carbon dioxide content of the air. The respiration of both plants and animals also increases it. A man, for example, exhales about 500 cc. of air at every breath; of this air 20 cc. is carbon dioxide.

Respiration. Respiration is the slow burning, or oxidation, of food in the cells of the body with the release of carbon dioxide, water, and heat energy. Like an engine, an animal needs fuel to do work. The fuel of an engine may be coal or gasoline; the fuel of an animal is the carbon compounds in food. A warm-blooded animal needs food to keep its body at its normal temperature and to supply the energy it needs in order to remain alive and work.

The food we eat enters the alimentary canal, where digestive juices break it down into substances that can pass through the membrane of the intestine into the blood vessels. Once in the bloodstream, these substances are carried to cells in all parts of the body.

A respiratory membrane that covers the lungs allows the oxygen of the air to enter the bloodstream. This oxygen is carried to the cells, where it oxidizes the products of digestion, forming carbon dioxide and water and releasing energy. The carbon dioxide passes from the cells to the bloodstream, then through the respiratory membrane of the lungs, where it is exhaled. Thus *respiration is an oxidation process that takes place in the cells.*

The fact that exhaled air contains more carbon dioxide than inhaled air can be verified by the following experiment.

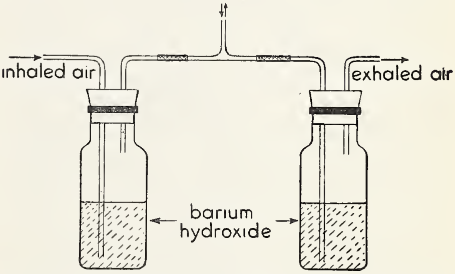


Fig. 29–1. Exhaled air gives a heavy precipitate with barium hydroxide.

Demonstration 29–1. To Compare the Carbon Dioxide in Ordinary Air with That in Exhaled Air.

Arrange two bottles containing limewater (or barium hydroxide) as shown in Fig. 29–1. The inlet and outlet tubes are so arranged that, when the T-tube is in the mouth, air can be drawn in through the left-hand bottle and expelled through the right-hand bottle. With the T-tube in the mouth, inhale and exhale about ten times.

The slight milkiness that forms in the left-hand bottle proves the presence of carbon dioxide in the air; the heavy white insoluble substance in the right-hand bottle shows that exhaled air contains a much higher percentage of carbon dioxide.

Carbon Dioxide in the Air. If the two processes of combustion and respiration were not counterbalanced by other processes in nature, the atmosphere would eventually be unable to support life. Human beings can live drowsily in an atmosphere containing 5 percent carbon dioxide, but they would die if this were increased to 10 percent. Actually the atmosphere contains very little carbon dioxide—0.04 percent to be exact, or four parts of carbon dioxide in 10,000 parts of air. The carbon dioxide content of the air is constant. A balance must exist therefore between the processes that evolve carbon dioxide and those that absorb it. These processes are known as *solubility effect* and *photosynthesis.*

The Solubility Effect. Carbon dioxide is constantly being removed from the air by the dissolving action of large bodies of water, such as rivers, lakes, and seas. Carbon dioxide does not merely remain in solution. It reacts with the water to form carbonic acid, a weak acid, which dissolves such rocks as limestone and chalk, known chemically as calcium carbonate. Even the small amount of carbon dioxide dissolved in rain water will do this. Though the dissolving effect is slight, the cumulative effect through the ages is considerable. Whole mountain ranges have been eroded in this way (see Chapter 10).

The calcium carbonate in solution is carried to the sea, where shellfish use it in building up their shells. The process does not end here, however, for the calcium carbonate is only "loaned" to the shellfish. When the shellfish die—there are thousands of species of them—their shells collect on the floor of the ocean. Here they are compressed and cemented together, and eventually they may be raised above sea level to form a mountain of chalk or limestone.

When limestone and chalk are heated in lime kilns they form lime, which is used in making mortar and plaster, and carbon dioxide is liberated. In this way a small percentage of carbon dioxide returns to the air and is again available for the various operations.

Photosynthesis. All animals depend on plants for their food. Out of the basic compounds produced in plants, animals build up the complex substances that make up their bodies. In the words of the prophet Isaiah, written in the 8th century B.C., "All flesh is grass."

Plants alone are capable of producing the world's food supply. For more than a century botanists, chemists, and physicists have tried without success to duplicate the reactions that plants perform naturally. The secret that the scientist is most eager to learn is the manufacture of glucose, a simple sugar, from the carbon dioxide and water of the air; that is,

carbon dioxide + water → glucose + oxygen

Glucose is a carbohydrate, that is, a compound of carbon, hydrogen, and oxygen, the hydrogen and oxygen being present in the same proportions as in water. Glucose is the basic material from which the plant makes the more complex carbohydrates, namely, starch and cellulose. Starch, the chief constituent of corn, wheat, and potatoes, is the main source of energy in food. Cellulose, on the other hand, is the woody material in every tree. Cotton, too, is almost pure cellulose.

In other words, the process of manufacturing glucose in plants provides food and fuel for man; without it life on earth, as we know it, could not exist. It is the most important of all chemical reactions. By what chemical means are carbohydrates made from carbon dioxide and water? Because sunlight is essential, the process is called *photosynthesis.* (*Photosynthesis* is derived from the Greek and means to *"put together by light."*) Chlorophyll, the green "blood" in grass and leaves and stalks, plays a large part in photosynthesis. Chlorophyll is a *conveyer* of energy which it receives in the form of sunlight and passes on to cause the reaction. Chlorophyll itself is not affected chemically in the process. It serves simply as a catalyst to speed up the chemical reaction, just as manganese dioxide acts as a catalyst in the preparation of oxygen (see page 206).

Plants breathe, like animals, and in breathing they take in oxygen and give out carbon dioxide. In sunlight, however, the photosynthesis reaction is much faster than the combustion reaction. A plant's breathing must therefore be observed while the plant is in a dark room. A method of doing this is described in the project at the end of this chapter.

Demonstration 29–2. To Extract Chlorophyll from Green Leaves.

Place some green leaves or grass in a flask. Pour a little alcohol into the flask, stopper the flask, and shake it. Now pour the alcohol into a test tube. Notice that it is green; chlorophyll has dissolved in the alcohol.

Photosynthesis and Combustion. *Photosynthesis is the reverse of combustion or respiration.* Expressed as a word equation, the photosynthesis reaction is

carbon dioxide + water + light → carbohydrate + oxygen

The combustion reaction is

fuel (carbohydrate) + oxygen → carbon dioxide + water vapor + heat

In photosynthesis, carbon dioxide is used up and oxygen is liberated; in combustion, oxygen is used up and carbon dioxide is liberated. In photosynthesis, light energy is taken in; in combustion, heat energy is given out. In other words, growing plants not only remove carbon dioxide from the air, but at the same time they replenish the air with oxygen.

The Control of Photosynthesis. Will the chemist soon learn the mechanism of photosynthesis so that he will be able to make sugar, starch, and cellulose? The reply to this question is that some progress has been made toward a solution of this problem.

A knowledge of the processes of photosynthesis would result in profound changes in our civilization. Synthetic foods would be produced in abundance; fuels also would be made quickly and cheaply. Indeed, photosynthesis would provide a new way of harnessing sunlight for electrical power.

The Carbon Dioxide Cycle. We have seen that carbon dioxide circulates in nature. Starting from the air and tracing a molecule of carbon dioxide over a long period of time, we see that it can engage in various activities. It might enter a starch molecule, and if the starch is digested by an animal, it would be released during respiration. It could then dissolve in water, and become part of the shell of an animal; and then, for ages, it might be trapped as limestone in a mountain range. Finally, it might be released by heat, when it would again be available for other operations. This continuous circulation is referred to as the *carbon dioxide cycle*. Fig. 29–2 shows still other journeys that the molecule might take.

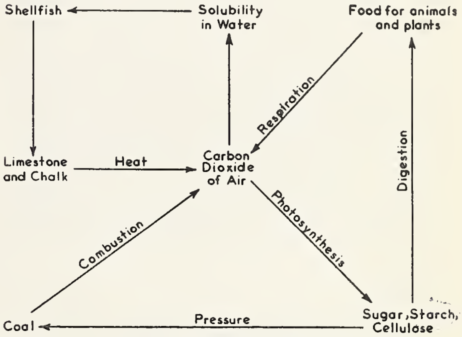


Fig. 29–2. Carbon dioxide cycle showing exchange and use of carbon dioxide in nature.

Atmospheric Conditions in the Carboniferous Period. Let us now return to the swampy forests of the Carboniferous period, the forests of ferns and club mosses from which modern industries have evolved. Why was this the age of coal? And why has no other age produced coal in such quantities? We know that the lush growth of the Carboniferous extended over the earth, and tree ferns flourished within a few degrees of the poles. The air was composed mainly of carbon dioxide and nitrogen; there was little oxygen, but a great deal of moisture. The heavy blanket of carbon dioxide and moisture prevented the earth's heat from escaping. Tropical conditions therefore existed even in the present temperate zones. These conditions favored luxuriant growth. But this growth reduced the amount of carbon dioxide in the air and increased the amount of oxygen. In this way the composition of the air gradually changed so that it could support life on the land.

Then came the glaciers from the South Pole. They came much earlier and advanced much nearer the equator than those from the north. Waters of the earth became trapped in ice fields, the levels of oceans fell, marshes dried up, and the air lost its steamy moisture. As the glaciers advanced, the cold dry winds blasted the jungles of fern and club moss, which could not withstand these hard conditions. So ended the period of the Carboniferous plants.

Energy in Fuels. The wheels of industry are turned by energy. Whether it is obtained from coal or gasoline, this energy has come to us from the sun. The heat energy we get from the combustion of coal or gasoline is the released energy of the sun that came to the earth in past ages. Today we are drawing upon the earth's savings of coal and oil. Eventually the stock will be exhausted. We are living beyond our means in terms of energy, like the man who draws heavily upon his savings instead of managing on his current income. A solution to the photosynthesis problem is therefore urgent. When scientists have found it, the world will have ample fuels from current supplies.

THINGS TO REMEMBER

Respiration is the slow oxidation of food material in the cells of the body with the release of carbon dioxide, water, and heat energy.

Air contains about *0.04 percent carbon dioxide.*

Combustion and respiration tend to increase the amount of carbon dioxide in the air; *photosynthesis and solubility* in water tend to reduce it.

Photosynthesis is the making of carbohydrates from carbon dioxide and water by means of chlorophyll and sunlight. It is an operation in nature, not a laboratory reaction.

The circulation of carbon dioxide in nature is called the *carbon dioxide cycle.*

QUESTIONS

A

1. Explain the terms: (*a*) carbohydrate; (*b*) photosynthesis; (*c*) respiration.
2. What is a catalyst? Give an example.
3. What is chlorophyll? Describe its use.
4. In the air, what is the percentage of: (*a*) oxygen; (*b*) carbon dioxide?
5. Name the factors that tend to increase the carbon dioxide in the air, and those which tend to decrease it.

B

6. Explain the process of respiration.
7. Explain how a limestone mountain may provide lime for the shells of sea animals.
8. (*a*) Write an equation for the photosynthesis reaction.
   (*b*) Compare photosynthesis and combustion.
9. What is the carbon dioxide cycle? Explain.

10. Explain the cause of the luxuriant plant growth in Carboniferous times.

11. Discuss some of the benefits that will result when scientists are able to carry out the photosynthesis reaction.

PROJECTS

1. *To Show That Starch Is Formed in Leaves in the Presence of Sunlight.* Shield two or three leaves of a potted geranium from light by an envelope of black paper. The black paper used to wrap photographic paper is satisfactory for this purpose. The black wrapping should be put in place during the afternoon of one day and the plant left to grow in the light during the next day.

During the afternoon of the second day cut from the plant a leaf that has been exposed to light and also one that has been wrapped in black paper. Drop the leaves into hot water and leave them for about five minutes.

Now place the two leaves in separate petri dishes. Spread them out gently, being careful not to tear them. Cover them with alcohol to extract the chlorophyll. After the chlorophyll is extracted, both leaves are completely discolored, and, judged by outward appearances, they look alike. The following chemical test, however, will distinguish between them.

A drop of tincture of iodine turns a starch solution blue; tincture of iodine can therefore be used to indicate the presence of starch. Leaving only a small quantity of alcohol in each petri dish, add from 2 to 4 drops of iodine tincture and mix well by rocking the dishes. A dark blue color develops rapidly in the leaf that has been exposed to light but not in the leaf that has been kept in the dark. What conclusion can you draw from this experiment?

This operation should be repeated on the afternoon of the third day to confirm this result.

2. *To Show the Breathing of Plants.* Place small whole plants in each of two jars (Mason jar type). Seal the jars tightly and place one in a dark room and the other in sunlight. After two or three days test the air in each jar for carbon dioxide. To do this, dip a glass rod in limewater and hold the end in one of the jars. Repeat the test for the other jar. The limewater turns milky only in the jar that has been in the dark room. What does this experiment prove?

REVIEW QUESTIONS ON UNIT 5

A

1. With what do you associate the following names: (*a*) Williams; (*b*) Bessemer; (*c*) Davy; (*d*) Nobel; (*e*) Perkin?

2. Which fuel do you associate with each of the following provinces: (*a*) Alberta; (*b*) Saskatchewan; (*c*) Ontario?

3. Which fuel do you associate with each of the following countries: (*a*) England; (*b*) Canada; (*c*) Iraq; (*d*) Russia; (*e*) Venezuela?

4. What event do you associate with each of the following cities: (*a*) London; (*b*) Cordova; (*c*) Moscow; (*d*) Baltimore; (*e*) Lambton County?

5. State the meanings of the following words: (*a*) photosynthesis; (*b*) seismograph; (*c*) curfew; (*d*) lignite; (*e*) cracking.

6. Define the terms: (*a*) kindling temperature; (*b*) fractional distillation; (*c*) destructive distillation; (*d*) hydrocarbon; (*e*) carbohydrate.

7. State the composition of the following: (*a*) water gas; (*b*) natural gas; (*c*) coke; (*d*) gasoline.

8. How are the following transported: (*a*) crude oil from Edmonton to Sarnia; (*b*) natural gas from Alberta to Montana?

9. State the nationalities of the following scientists: (*a*) Lavoisier; (*b*) Nobel; (*c*) Bunsen; (*d*) Watt.

10. Write a significant statement about each of the following: (*a*) Prometheus; (*b*) the "Eternal Fires"; (*c*) Carboniferous period; (*d*) alchemy.

11. Describe chemical tests by which you could recognize oxygen and carbon dioxide.

12. (*a*) What is a catalyst? (*b*) Give an example.

13. State which of the following materials are combustible: hydrogen, oxygen, wood, carbon tetrachloride, kerosene, nitrogen, carbon dioxide.

B

14. If both powdered coal and gunpowder are strongly heated out of contact with the air, what would be expected to happen in each case?

15. Compare the formation of coal with that of oil.

16. Which is the best method of extinguishing: (*a*) a coal fire; (*b*) a small gasoline fire; (*c*) a fire of natural gas burning at the end of a pipe? Give reasons for your answers.

17. Coke, water gas, and gasoline all liberate heat when they combine with the oxygen of the air. Explain how, in each case, man has used this source of heat to his own advantage.

18. What is the difference between a luminous and a nonluminous Bunsen flame? Which is the hotter? Why?

19. What three different types of illumination have been used by coal miners? Which are safe and why?

20. (*a*) Name the three fire extinguishers that use carbon dioxide as the extinguishing agent.
(*b*) How is the carbon dioxide generated in each case?

21. Describe briefly the three methods by which gasoline is obtained in industry.

22. Of the following pairs which would you say is the more important substance: (*a*) natural gas or hydrogen; (*b*) coal or oil? Why?

23. (*a*) How does fractional distillation differ from ordinary distillation?
(*b*) Why does lubricating oil condense near the bottom of the tower and gasoline condense at the top?

24. (*a*) What is destructive distillation?
(*b*) Why is the destructive distillation of coal an important industrial process?

25. Why were the conditions of the Carboniferous period more favorable than present-day conditions for the formation of coal?

26. (*a*) Draw and label the parts of a candle flame.
(*b*) Write an equation for the reaction in the flame.
(*c*) Explain briefly how you would test for the products formed in this flame.

Carbon dioxide

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Unit 6

POWER FROM COMBUSTION

30. MACHINES
31. STEAM ENGINES
32. INTERNAL-COMBUSTION ENGINES
33. THE AIRPLANE
34. GAS TURBINES, JETS, AND ROCKETS

Chapter 30

MACHINES

In our civilization we take complex machines, such as a newspaper printing press or a power generator or a steam shovel, more or less as a matter of course. It took man centuries to develop the complex machines that respond to the touch of a button or the pressure on a lever. But all our modern machines, however complex, are adaptations of six simple devices that were in use three thousand years ago. These simple machines are the inclined plane, the screw, the wedge, the lever, the pulley, and the wheel and axle.

Probably the oldest machine is the *lever*. The simplest lever is a plain stick. When a primitive man used a stick to pry rocks out of the ground, he was using his stick as a lever. The advantage of the lever is that it can be used to lift heavy weights with the application of a small force. About 220 B.C. Archimedes recognized the possibilities of the lever when he exclaimed, "Give me a lever long enough, and a fulcrum strong enough, and single-handed I can move the world."

Long before the time of Archimedes, however, much construction was done with the aid of simple machines. The best-known example is the Great Pyramid in Egypt, which was built more than five thousand years ago. This structure, which was 481 feet high, was erected with the aid of inclines, wedges, and pulleys. Though it is a monument to the knowledge and skill of the engineer, it is also a monument to the barbarity of the times. According to one historian, 100,000 slaves worked for 20 years in the construction of the Great Pyramid, and many thousands lost their lives while working. In contrast, the Hoover Dam, which is larger than the Great Pyramid, was built by 1,200 men in 21 months.

These data show clearly the difference between the effectiveness of the simple machines used by the ancients and that of the machines in use today. Early machines increased the scope of human or animal effort. They had to be operated by muscular effort but they reduced the force that had to be applied to do the task. This was true of all machines with the exception of water wheels and windmills and other devices which depended on forces in nature—wind and water power. The modern machine, however, does far more than reduce muscular effort. It can be operated almost without human effort. The locomotive, the internal-combustion engine, and the electric motor, for example, eliminate muscular effort almost entirely.

Work. *A machine is any device that aids man in doing a task.* Since a task involves work, before studying machines, you must understand what the scientist means by the term "work."

Most people probably believe that when they are pulling and pushing something they are doing work. But to a scientist, pulling and pushing are not necessarily doing work. Let us see why. If a boy tugs on a heavy box but is unable to move it, he may be exerting a large force, and may get very tired, but he has not done work. But if he exerts a force that pushes the box to another place, he is doing work. *Work involves both force and distance.*

Consider another example. Suppose that you are carrying a heavy suitcase along the platform of a railway station. Your arm is exerting an upward force to hold up the suitcase, but the force does not move the suitcase. Because the suitcase does not move in the direction in which the force is applied, you are not doing work. If you carry the suitcase up a ladder, however, you are moving the suitcase upward in the same direction as the force you are applying. Now you are doing work. Only when a *force produces motion* is work done, and the *work is the product of the force and the distance through which that force moves.* That is,

$$\text{Work} = \text{force} \times \text{distance}$$

Work is expressed in units that are combinations of simple force and distance units. A common unit of work is the *foot-pound.* If a boy tries to push a trunk across the floor with a force of 40 pounds and fails to move it, he does no work. If he moves it one foot, he does 40 foot-pounds of work; if he moves it 10 feet, he does 400 foot-pounds of work. A locomotive, on the other hand, exerts forces measured in tons and covers distances measured in miles. The work unit to describe such work is the *ton-mile.*

Power. *Power is the rate at which work is done.* The shorter the time required to do work, the greater the power. If, in the example above, the boy pushes the trunk 10 feet in 5 seconds, he is exerting more power than if he does the same job in 20 seconds. If it takes him 5 seconds to do the job, his rate of doing work is

$$\begin{aligned}\text{Power} &= \frac{\text{force} \times \text{distance}}{\text{time}}\\ &= \frac{40 \times 10}{5}\\ &= 80 \text{ foot-pounds per second.}\end{aligned}$$

If he takes 20 seconds, his power is only $\frac{40 \times 10}{20}$, or 20 ft-lb/sec.

The amount of work done is the same in both instances, but the power is much less in the second instance.

Notice that the unit of power is derived by dividing the unit of work by the unit of time. What power unit might well be used for locomotives?

Horsepower. Another method of expressing power was developed in the early days of the Industrial Revolution, when steam engines first replaced horses as the source of power in mills and factories. Experiments made by James Watt, the inventor of the modern steam engine, showed that a good horse could do 550 foot-pounds of work per second. This rate Watt called one *horsepower.* His 4-horsepower engine could replace four horses and do 4 × 550, or 2200 ft-lb/sec. Some modern automobile engines develop over 100 horsepower.

A boy can test his horsepower by a simple experiment. If he knows his weight and the vertical height of a flight of stairs, he can calculate his horsepower by finding out how long it takes him to run up the stairs. If he weighs 150 pounds and runs up a flight of stairs 44 feet high in 15 seconds, his horsepower is found as follows:

$$\begin{aligned}H.P. &= \frac{150 \times 44}{550 \times 15}\\ &= \tfrac{4}{5}\ h.p.\end{aligned}$$

The power needed for a job is just as important as the work to be done. If a ditch must be dug, ten men can do it more quickly than one man because their combined power is ten times as great as that of one man. If the ditch must be dug quickly, to drain a flooded region for instance, the greater power of the ten men is economically important. And a machine that can do the same job even more rapidly is still better.

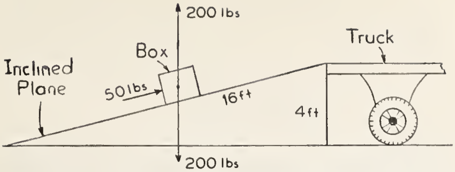


Fig. 30–1. On a frictionless inclined plane the work input equals the work output. The work input here is 50 lb. × 16 ft., and the work output is 200 lb. × 4 ft.

Simple Machines. The force required to do a job is often greater than a human being can exert. Usually one of the simple machines can provide the necessary force. Then the man exerts a force on the machine, using such strength as he has, and the machine transforms this applied force, or effort, into a more useful, larger force. *The work done by the machine (output), however, cannot be greater than the work put into it (input).*

The Inclined Plane. One of the simple machines used in lifting weights is the *inclined plane.* Suppose a box weighing 200 pounds is to be lifted from the ground to the body of a truck 4 feet above the ground. The work required to lift 200 pounds through 4 feet is 800 foot-pounds. The average man cannot lift 200 pounds through 4 feet. Then how can the job be done?

One method is to make an inclined plane by placing one end of a long board on the ground and the other on the truck, and then pushing the box up the slope.

We can analyze this machine by studying the work output and the work input as shown in Fig. 30–1. Remember that the work to be

Courtesy Public Roads Administration

Fig. 30–2. Rowena loops on the Columbia River Highway, Route 30, between Hood River and The Dalles, Oregon.

done, that is, the output, is 800 foot-pounds. The machine cannot reduce the work required to get the box onto the truck. (For simplicity we shall disregard friction.) The force exerted along the length of the plane must therefore be sufficient to do 800 foot-pounds of work. Suppose the board is 16 feet long. Then the work input will be the unknown force (F) times the distance moved (16 feet), and this must equal the output (800 foot-pounds):

$$F \times 16 = 800$$
$$F = 50 \text{ lb.}$$

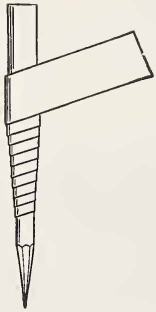


Fig. 30–3. A screw is an inclined plane wrapped around a rod.

In other words, a push of 50 pounds along the whole length of the 16-foot plank will do the same amount of work as a force of 200 pounds exerted directly upward through 4 feet. *In a frictionless machine the work output equals the work input. If a machine increases the force that is applied to it, the motion will be reduced.*

Mechanical Advantage. An inclined plane is clearly a useful device. We describe the degree of usefulness by the ratio of the resistance, or force overcome, R, to the effort, or force applied, E. This ratio is called the *mechanical advantage* (M.A.) of the machine, a term already discussed in Chapter 7. For the inclined plane mentioned above, the mechanical advantage is shown in the following equation.

$$\text{M.A.} = \frac{200}{50} = 4$$

Roads running up the sides of mountains often fold back and forth in hairpin turns so that they will form several inclined planes and thus provide the greatest possible mechanical advantage for automobiles in climbing. For the same reason, a boy finds it easier to ride a bicycle up a steep hill if he steers back and forth across the road.

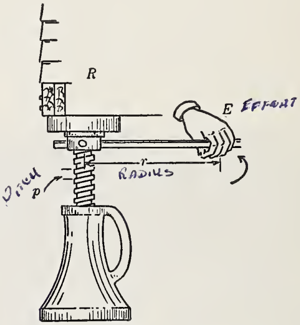


Fig. 30–4. Builder's jackscrew.

Screws. A *screw* can be thought of as an inclined plane wrapped around a rod, as shown in Fig. 30–3. Thus a builder's jackscrew, like the one in Fig. 30–4, lifts a building of weight R by the distance between threads p when the screw is turned one revolution. This distance is called the *pitch* of the screw. The force E applied to the handle moves through the circumference of the large circle of radius r. Therefore, in one complete turn, the work input is $E \times 2\pi r$ and the work output is $R \times p$. If friction is small, these are equal:

$$E \times 2\pi r = R \times p$$

Thus a force of 50 pounds moving in a circle whose radius is 2 feet can raise a load of over

29,000 pounds if the pitch of the screw is $\frac{1}{4}$ inch, or $\frac{1}{4} \times \frac{1}{12}$ feet:

$$50 \times 2\pi \times 2 = R \times \tfrac{1}{4} \times \tfrac{1}{12}$$
$$R = 29{,}144 \text{ lb.}$$

In reality, friction would reduce this figure to less than half the value shown. Though friction increases the work required to operate a machine, it is often very helpful. In this case it prevents the screw from turning backwards as soon as the effort is removed. Without friction screws would not hold in wood, nor would nuts stay tight on bolts.

Other Uses of Screws. Boat and airplane propellers are screws that move through water and air respectively. The blades of an airplane propeller, for instance, move with circular sweeps, as shown in Fig. 30–5, and push against the air with sufficient force to move the airplane forward.

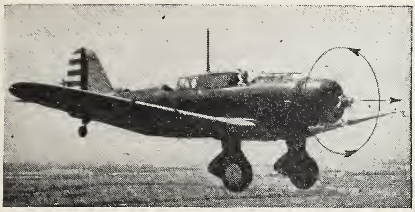

Courtesy U.S. Army A.A.F.

Fig. 30–5. The blades of an airplane propeller act like a screw moving through air, pulling the airplane after it.

Wedges. The wedge, commonly used to split wood (see Fig. 30–6) is really a short inclined plane. The long sides of the wedge move into the wood and separate it by a short distance. Tremendous splitting forces can be developed from hammer blows on the end of the wedge. But again, friction is so great that the forces cannot be easily computed.

Machine drills and wood bits are combinations of simple screws and wedges used for cutting holes. The cutting edge of the tool is the wedge and the screw is the part that removes the material. The coal face in a mine, for instance, is bored with large screws which make deep holes to receive the explosive charge.

The Lever. The *lever* is another simple machine. It has many forms and is very useful. A crowbar, for example, is a simple lever used in moving heavy weights. When a man wants to lift a heavy object, he puts the tip of the bar under the object and raises the handle of the bar. Let us consider the work done by the man and the work done by the crowbar. Suppose the bar is 5 feet long and the load rests on the bar 6 inches from the end (see Fig. 30–7). If the upward force exerted upon the load is 300 pounds (known as the *resistance*), the work done in lifting it 2 inches is 600 inch-pounds. The equivalent work (neglecting friction) must be done by the man. But to raise the load 2 inches he must raise the crowbar 20 inches, as shown in Fig. 30–7. Let us see how great a force (called the *effort*) he must exert to do 600 inch-pounds of work.

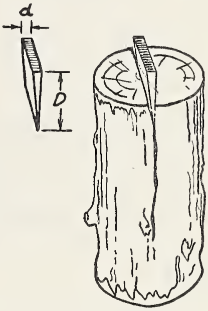


Fig. 30–6. The wedge is a form of inclined plane.

$$E \times 20 = 600$$
$$E = 30 \text{ lb.}$$

In this example a force of 30 pounds can lift a load of 300 pounds. The mechanical advantage of the crowbar therefore is 300/30, or 10. The point about which the motion occurs is called the *fulcrum*. In this case, it is the end of the crowbar. Note that the ratio of the

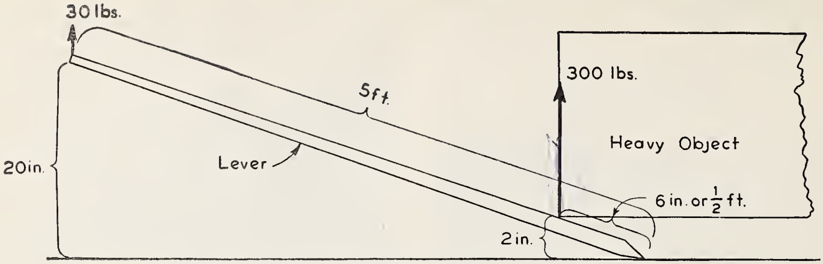


Fig. 30–7. A crowbar is a machine for lifting heavy weights a short distance.

distance between the fulcrum and the load (½ foot) and the distance between the fulcrum and the handle (5 feet) is 1:10. That is, the forces *E* and *R* are inversely proportional to their distances from the fulcrum. The nutcracker is a lever of the same type as the crowbar. Can you identify the fulcrum, the effort, and the resistance in Fig. 30–8?

A second type of lever is illustrated in a pair of scissors. In this lever the fulcrum is near the middle, at the joint between the handles and the blades. When an effort is applied at the handles, the resistance of a piece of paper is overcome by the blades. The forces depend, again, on their distance from the fulcrum. If the paper resists with a force of 2 ounces at a point 3 inches from the fulcrum, then a force of 3 ounces must be exerted on the handle at a point 2 inches from the fulcrum. Can you express this in the form of an equation?

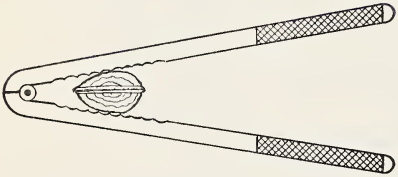


Fig. 30–8. Can you point out the fulcrum, effort, and resistance when this lever is being used to crack a nut?

Compare the action of tin snips used for cutting sheet metal with that of paper shears, as shown in Fig. 30–9. In which case is the effort closer to the fulcrum than the resistance? Which would have the greater mechanical advantage? Is this necessary? Is it reasonable?

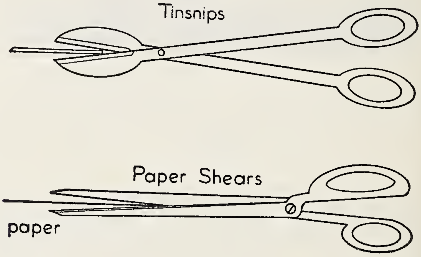


Fig. 30–9. The action of tin snips and paper shears.

The Fixed Pulley. A lever has one great disadvantage: the distance through which it can move is limited. For instance, the short end of a lever like the one shown in Fig. 30–10 is sometimes used on farms to lift a bucket of water from a well. But this system cannot be used when the well is deep, because the lever cannot raise the bucket through a sufficient height. If a second lever could be added to the first, however, to take over when the first became useless, the amount of motion would be increased. And with three or four levers, as in Fig. 30–11, still more distance could be covered. Such a multiple lever system is actually a *pulley,* in which the rope

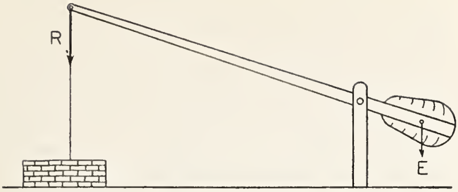


Fig. 30–10. A simple lever helps lift water from a well.

comes up one side and goes down the other.

A simple fixed pulley of this type is shown in Fig. 30–12. With such a pulley a man on the ground, by pulling down, can lift a load of hay into the loft of a barn. The force he exerts is exactly equal to the weight of the load of hay. The pulley merely enables the man to raise the load to a higher position by pulling down rather than by lifting up. What is the mechanical advantage of such a pulley?

The Movable Pulley. There are other methods of running ropes through pulleys that make them still more useful. For instance, the load to be raised may be tied to the axle of the pulley, as in Fig. 30–13. Then one end of the pulley rope is tied to a strong support and the other end is pulled upward. A simple experiment shows that by this device nearly twice as heavy a load can be lifted as with a fixed pulley.

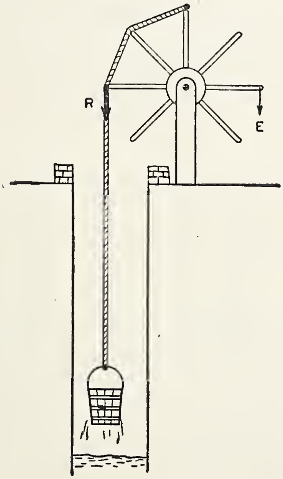


Fig. 30–11. Several levers will increase the distance moved.

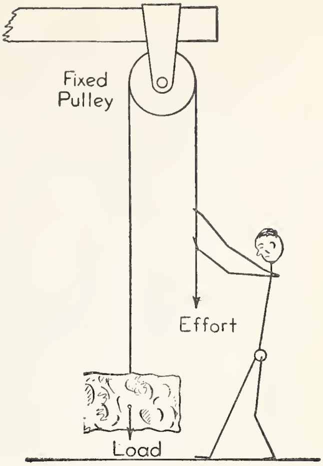


Fig. 30–12. A fixed pulley changes the direction of a force.

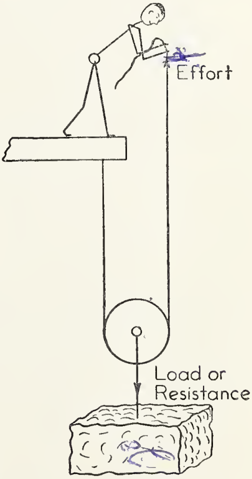


Fig. 30–13. A movable pulley goes with the load.

Demonstration 30–1. The Movable Pulley.

Arrange a pulley system as shown in Fig. 30–14. Hang a 1000-gram load on the pulley, and attach a spring balance (reading zero to 2000 grams) to the free end of the string. Read the balance while the load is slowly being lifted. Raise the balance 10 inches, and measure the distance through which the load moved.

What is the effort applied to this machine? What is the resistance? What is the mechanical advantage of a single movable pulley? How does the distance moved by the effort compare with the distance moved by the load? How does a movable pulley differ from a fixed pulley?

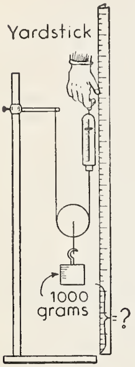


Fig. 30–14. Experimental arrangement for testing a movable pulley.

With a movable pulley the spring balance should read one half as much as the load. This can be explained by comparing the pulley with a lever, as shown in Fig. 30–15. The effort is applied at *E*, the resistance is at *R*, and the fulcrum is at *O*. Therefore the effort is twice as far from the fulcrum as is the resistance, and must move twice as far when the load is raised. The work output ($R \times h$) equals the work input ($E \times d$), from which we see that if d is twice the distance h, then the effort E is one-half the resistance R. Thus the mechanical advantage of a movable pulley is 2.

Combinations of Pulleys. When a farmer lifts hay into the loft of his barn, it is more convenient to pull the rope down than up. This can be accomplished by combining a fixed pulley with the movable one, as in Fig. 30–16. The fixed pulley merely changes the direction of the rope. The mechanical advantage of the combination is the same as that of a movable pulley, that is, 2. The usefulness of the system, however, is increased.

If the rope from the fixed pulley is passed through a second movable pulley, which also supports the load, as in Fig. 30–17, the mechanical advantage becomes 2 × 2, or 4. What effort is required in this case to lift a 1000-gram load? How far must the effort be moved to lift the load 5 inches?

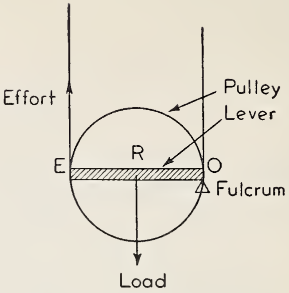


Fig. 30–15. A movable pulley is like a lever with a fulcrum at one end. The mechanical advantage is 2.

More fixed and movable pulleys may be added to the system. But more than six of each kind makes a clumsy arrangement, and other types of machines are more useful.

Wheel and Axle. Another simple machine consists of two pulleys of different diameters fixed firmly to the same shaft, as shown in Fig. 30–18. The load is hung from a rope wound around the small pulley, usually called the *axle*; effort is applied to the rope on the large

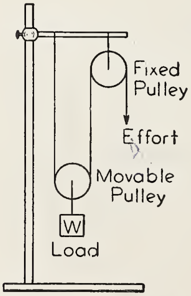


Fig. 30–16. The mechanical advantage of this system is 2.

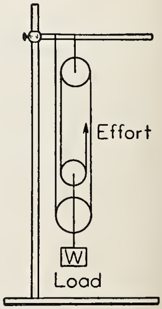


Fig. 30–17. The mechanical advantage of this system is 4.

pulley, usually called the *wheel*. If the effort causes the wheel to make one complete rotation, the effort will move a distance equal to the circumference of the wheel, while the load will be lifted a distance equal to the circumference of the axle, a much shorter distance. We know that work input equals work output.

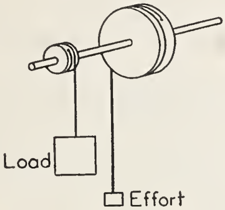


Fig. 30–18. A small effort can lift a large load on drums of different size.

Therefore the greater the distance moved by the effort, the smaller the force needed to lift a large load.

If the circumference of the wheel is 20 inches and that of the axle is 2 inches, then the distances moved by the effort and load respectively will be in the ratio of 20 to 2.

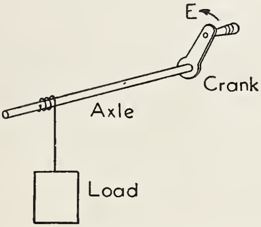


Fig. 30–19. A crank and axle makes a good machine.

Thus, neglecting friction, the mechanical advantage of the system is 20/2, or 10. In other words, a 5-pound force at E could lift a 50-pound load. How would you express the mechanical advantage of a wheel-and-axle system in terms of the radii of the wheel and axle?

The large pulley, or wheel, may be replaced by a crank, and the small pulley may become the axle itself, as in Fig. 30–19. Different forms of wheel and axle are used to lift buckets of water from wells, to tighten ropes on a boat, and to pedal bicycles.

Belts and Gears. Belts running continuously over pulleys are used to transmit power from an engine to a machine, such as a circular saw.

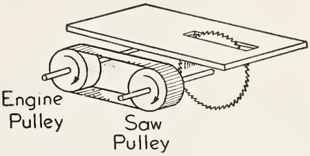


Fig. 30–20. With pulleys of the same size, the saw goes at the same speed as the motor.

If the pulleys are the same size, as in Fig. 30–20, there is no change in speed or force, and the mechanical advantage is 1. But if the pulley on the engine is larger than that on the saw, as in Fig. 30–21, the saw rotates more rapidly than the engine, but with less force than when the pulleys are the same size. The

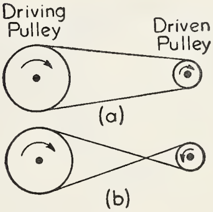


Fig. 30–21. Pulley and belt systems which increase speed. In *a* the direction of rotation is not changed; in *b* it is reversed.

reverse is true if the pulley on the saw is larger than that on the engine. In other words, *what is gained in force is lost in speed.* The belt may be replaced by a chain, and the pulleys by gears. Such an arrangement is used to drive the rear wheel of a bicycle. Can you tell by examining Fig. 30–22, whether the rear wheel will go faster or slower than the pedals? The links of the chain fit over the teeth of the

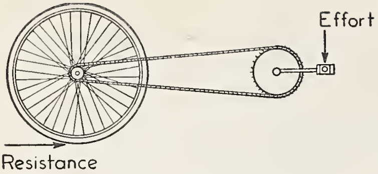


Fig. 30–22. A bicycle wheel is driven by a combination of three simple machines. Can you identify each in the diagram?

gears. The large gear of a bicycle usually has 49 teeth and the small gear 18. The mechanical advantage of this system is $\frac{18}{49}$, or 0.36. A mechanical advantage less than 1 indicates high speed and a decrease in force. In many instances, as in the gear systems of automobiles, there is no chain and the teeth of one gear drive the teeth of the other. In Fig. 30–23, the large gear is driving the small one. What applies to gears and chains is equally true for gears alone. Can you figure out the mechanical advantage of the gear systems in Fig. 30–24? If the first gear goes clockwise, which way will the last gear rotate?

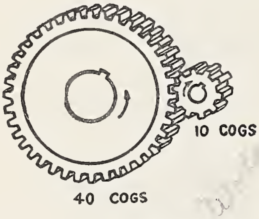


Fig. 30–23. Automobile gears.

Efficiency. The ability of a machine to do a job without great loss of work in overcoming friction is called the *efficiency of the machine. Efficiency is the ratio of the work done by the machine to the work put into it.* Or:

$$\text{Efficiency} = \frac{\text{useful work output}}{\text{work input}}$$

Since the useful work output is always less than the work input, the efficiency is always less than 1; it is usually expressed as a percentage.

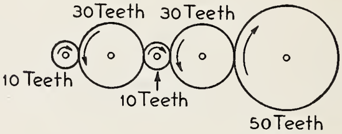


Fig. 30–24. Several gears in line make a gear train. Can you tell the speed of each gear compared with the first one?

Let us return, for an example, to the inclined plane discussed earlier on page 271. Suppose that, because of friction, a force of 60 pounds instead of 50 pounds is required to push the box up the plank. The work output is the same, that is, 800 foot-pounds; but the input is 60 × 16, or 960 foot-pounds. The efficiency of the machine is therefore $\frac{800}{960}$, or 83.3 percent.

THINGS TO REMEMBER

A *machine* is any device that aids man in doing a task.

All machines are *combinations* of the lever, pulley, wheel and axle, wedge, screw, or inclined plane.

Work equals the product of a force and the distance through which it moves.

Power is the rate of doing work.

One *horsepower* is 550 foot-pounds per second.

The work obtained from a simple machine cannot be greater than the work put into it.

If a machine increases the force that is applied to it, the motion produced will be reduced; if it decreases the force, the motion will be increased.

Friction reduces the efficiency of a machine.

The *efficiency* of a machine is the useful work output divided by the work input.

Power can be *transmitted* by belts, chains, or gears.

Gloria Cream

QUESTIONS

A

✓**1.** What is a machine?

✓**2.** Define the term *work*.

✓**3.** What *units* are commonly used for work? ft lb ✓ Ton-mile

✓**4.** How much work is done by a 150-pound boy in climbing stairs 20 feet high? 3000 ft lbs

✓**5.** Define the term *power*.

✓**6.** How many foot-pounds per second equal one horsepower?

✓**7.** How does *power* differ from *work?*

8. Define the term *efficiency*.

9. Draw a diagram of a lever with a fulcrum between the effort and the resistance. What might such a device be used for?

10. Draw a diagram of a pulley system with a mechanical advantage of 4, for use in hauling a boat up on a beach.

B

✓**11.** The terms *force* and *power* are often confused. How do they differ?

✓**12.** What must be the horsepower of an engine which lifts a 220-pound load of hay up 40 feet in 20 seconds?

13. Can a 2-horsepower engine lift as heavy a load as a 5-horsepower engine? Explain.

14. What is the efficiency of a jackscrew that does 400 foot-pounds of work when 1,000 foot-pounds are applied to it? 40%

PROJECT

Using a Pulley System. Obtain a set of two double pulleys of the size painters or mechanics use. Suspend them from the ceiling on a strong hook, as shown in Fig. 30–25. Use rope at least one-half inch in diameter.

Using the pulley system, lift a boy whose weight is known through a distance of 3 feet. Measure the effort with a strong spring balance, and measure the amount of rope used at the effort.

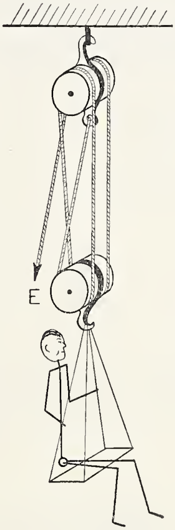
Compute the work input, the work output, and the efficiency of the system.

Repeat the experiment lifting a lighter boy. Is the efficiency the same? Can you explain this?

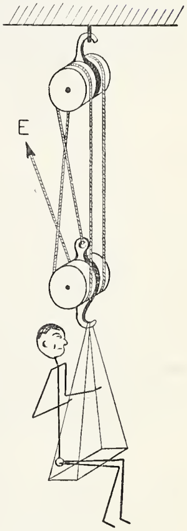
Also repeat the experiment with the ropes arranged as in Fig. 30–26. Is the effort more or less than in the previous system? Why is this? Does this arrangement have a different mechanical advantage? Can you explain?

Could *you*, with either of these pulley systems, lift a 600-pound cement block? Explain.

400
20
0 0



30–25



30–26

Fig. 30–25. A pair of double blocks and tackle can be arranged as shown. Here four ropes hold up the boy.

Fig. 30–26. With this pair of double blocks, five ropes hold up the boy. What is the mechanical advantage of this machine?

Chapter 31

STEAM ENGINES

Steam is a vital part of our modern industrial civilization. It is one of our chief sources of power. Many locomotives that carry passengers and haul freight to all parts of the country are operated by steam power. Steam is used also for stationary power, that is, for driving machinery in factories. Another important use of steam is to generate electricity, as we shall see in the next unit.

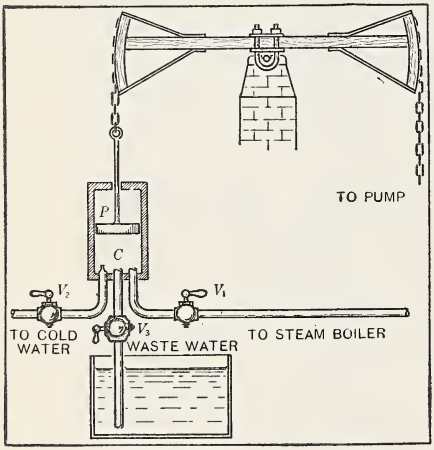


Fig. 31–1. Newcomen engine for pumping water.

Steam was not used as a source of power until the middle of the 18th century. About that time, particularly in England, coal mining was being developed and the pottery industry was being expanded. Pumps were needed in the coal mines to prevent flooding, and in the potteries to supply a steady stream of water to turn the mill wheels. An important question arose: Could steam be made to operate these pumps using coal as fuel? In other words, could a steam engine be built?

The first practical steam engine was invented about 1710 by an Englishman named Newcomen and was used to pump water out of coal mines. In this engine water in the boiler was heated by a coal fire to make steam, which entered the cylinder through valve V_1, as shown in Fig. 31–1. A spray of cold water was then injected into the cylinder through valve V_2. This caused the steam to condense, thereby reducing the pressure inside and allowing air pressure to push the piston down. The piston was then raised by a counterweight on the pump rod, while the water was drained from the cylinder through valve V_3. Then more steam entered the cylinder, and another injection of cold water caused the piston to fall again. It was this up-and-down motion of the piston that operated the pump.

The main fault with Newcomen's engine was the great waste of steam and consequently of coal, caused by the reheating of the cylinders after each injection of cold water. This objectionable feature was overcome by James Watt, a Scottish engineer. In 1776 Watt invented the steam engine which has made modern industrial civilization possible. Let us now consider the operation of a modern steam engine.

The Steam Engine. The steam engine may be a stationary one used for power in factories, for propelling ships, and for sawing timber in a forest; or it may be a steam locomotive. In both engines, however, the operation is the same: high-pressure steam is the source of the power. The steam is generated in a boiler and piped to a *cylinder*, where the energy of the steam is converted into motion and work. In other words, a steam plant consists of the two essential parts: boiler and cylinder.

The Steam Boiler. The heat of the fire converts water in the boiler into steam. The fire may be produced by burning wood, oil, or coal.

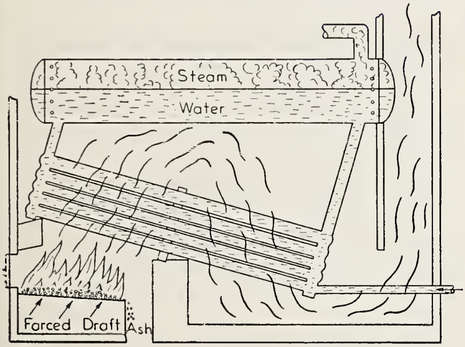
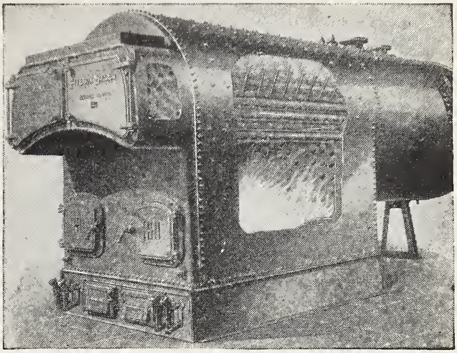


Fig. 31–2. A water-tube boiler with forced air draft and steam storage.

The firebox and boiler are carefully designed to produce as much steam as possible from the fuel used. Two types of boiler are in common use. In the *water-tube boiler*, the water is in tubes around which the fire burns; in the *fire-tube boiler*, the fire passes through tubes around which the water circulates.

In the water-tube boiler, shown in Fig. 31–2, long steel tubes are built into the top of the firebox, and the flames heat the water in the tubes until it turns into steam. The steam collects at the top of the boiler, where it is held until needed. As you can see in the illustration, the heat from the fire passes by the tubes several times so that the water gets as much heat as possible before the fumes finally go up the stack. Water-tube boilers are commonly used in powerhouses and in ships where their vertical height can be fitted easily into the available space.

The fire-tube boiler is usually a big steel tank with steel pipes running from one end of it to the other, as shown in Fig. 31–4. The fire from the firebox passes through the pipes and up the smokestack. Water circulates around the pipes and eventually turns into steam, which collects in the top of the boiler. Fire-tube boilers are used in locomotives. The long tubes get the maximum heat from the fuel gases. This is important because the more work the engine has to do, the more steam is required and the more fuel must be burned.



Courtesy Kewanee Boiler Corp.

Fig. 31–3. A fire-tube boiler.

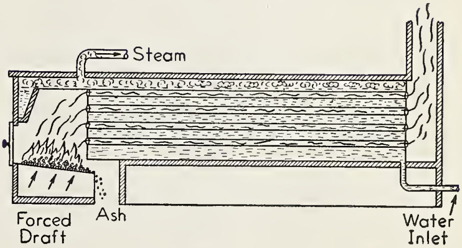


Fig. 31–4. Diagram showing the construction of a fire-tube boiler with forced draft.

The Cylinder. In all steam engines the steam from the boiler is fed through a large pipe to a cylinder where it does its work. The flow of steam is controlled by a large throttle valve. The cylinder shown in Fig. 31–5 is a steel tube C in which a tightly fitting piston *P* can slide back and forth. An automatic slide valve V controls the flow of steam into the cylinder so that it will push the piston in the right direction at the right time.

The operation of the cylinder can be followed easily by examining Fig. 31–5. Let us start with the piston at the right end of the cylinder. When the engineer opens the throttle valve, steam flows from the boiler, past the slide valve V, and into the cylinder, pushing the piston to the left. When the piston has gone about one-quarter of the way through the cylinder, the slide valve closes and the high-pressure steam in the cylinder expands, pushing the piston the rest of the way to the left. Just as the piston reaches the end of its stroke, the moving slide valve lets steam into the left end of the cylinder. This steam then pushes the piston to the right, forcing out the used steam through the exhaust hole X. When the piston reaches the end of this stroke, the moving slide valve lets steam into the right end of the cylinder and the action starts all over again.

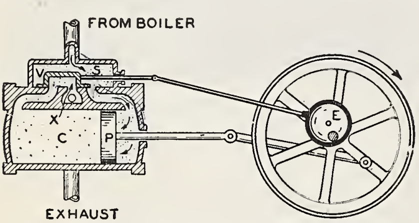


Fig. 31–5. Simple reciprocating steam engine.

The exhaust steam has a lower temperature and pressure than the steam in the boiler. This is due to the fact that the steam has expanded in the cylinder, doing work and thereby being cooled. In other words, *the work done by a steam engine comes directly from the expanding and cooling of steam*.

Some steam engines have a single-acting cylinder in which steam pushes from one side only. In such engines a heavy flywheel keeps the engine running while the piston pushes the used steam out the exhaust, so that only every other stroke of the piston produces power. Most large steam engines, however, use the double-acting type of cylinder in which the steam pushes first from one side, then from the other. This arrangement provides a smoother flow of power than can be obtained from the single-acting type. Both types are *reciprocating* engines, which means that the pistons move back and forth.

Work from Heat. Steam engines cannot do work by themselves. They convert energy from one form to another. The energy output of a steam engine is derived from the energy stored in coal or oil. This energy is the product of plants and animals of past ages.

The work that can be obtained from fuel depends on the heat energy produced when the fuel is burned and on the efficiency of the engine. Experiments show that 778 foot-pounds of work are equivalent to one B.T.U. of heat. Steam engines, of course, convert heat to work, and the same numerical relationship holds; that is, every B.T.U. of heat produced by the burning coal should give 778 foot-pounds of work.

Efficiency of Steam Engines. Steam engines are inefficient, however. In spite of insulation some heat is lost in the boiler, and much more is lost in the engine itself. The engine uses steam whose temperature is well above 100° C., and cools it to 100° C. by allowing it to expand. The expansion produces the work. The hotter the steam before expansion, the more efficient is the conversion by the engine of the energy of steam into work. For this reason modern engines use steam heated to about 200° C. at a pressure of 225 pounds per square inch.

To obtain a still greater efficiency, two or three cylinders may be used for the same steam. In such an engine high-pressure steam from the boiler enters the first cylinder and does some work by expanding a little. The same steam is then led into the next cylinder, where it does more work, and in the last cylinder it finally expands to its full extent. Such an arrangement is called a triple-expansion engine.

Condensers. A more efficient use of the steam is accomplished by reducing the temperature of the exhaust steam below 100° C. This can be done, however, only if a partial vacuum is produced in the exhaust line from the cylinder. Since steam below 100° C. has a pressure less than that of the atmosphere, it cannot escape from the cylinder against normal air pressure.

The exhaust steam itself is used to produce the vacuum. It is run into a tank where it is cooled by water and condensed. The volume of the condensed water is so much less than that of the steam that a partial vacuum is produced, thereby allowing the steam in the cylinder to expand more than usual and do more work.

Even with all these improvements and devices, the over-all efficiency of a steam locomotive is not much greater than 12 percent; and the efficiency of a stationary engine not much greater than 22 percent. Only because coal is cheap and abundant is it economical to operate such wasteful engines. As we shall see later, there are more efficient methods for producing work from heat, but they are not always economical if higher priced fuels are used.

Transmitting Power in an Engine. Changing straight-line motion to rotary motion is essential if the power of the steam in a cylinder is to be converted into useful work. This is true of the steam engine and also of the internal-combustion engine described in the next chapter. The action can best be compared with that of the knee and foot when riding a bicycle, as illustrated in Fig. 31–6. The knee moves up and down, and the mechanism of the foot and pedal converts this up-and-down motion into circular motion. Only circular motion is put into the bicycle pedals, which are connected to the rear wheel by a chain.

Similarly, the back-and-forth motion of the piston in an engine is converted into the rotary motion of the flywheel of a stationary engine, or of the wheels of a locomotive, by means of a piston rod, a connecting rod, and a crank. In addition, an *eccentric*, shown at *E* on the main shaft in Fig. 31–5, moves the slide valve to let steam in and out of the cylinder at just the right moments. The eccentric is a disk, or wheel, mounted off-center on the main shaft so that it wobbles as the shaft turns. The wobble moves the slide valve.

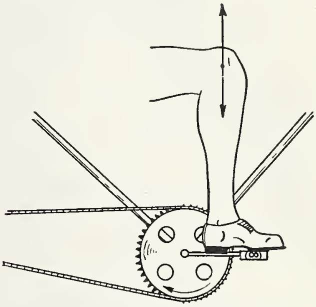
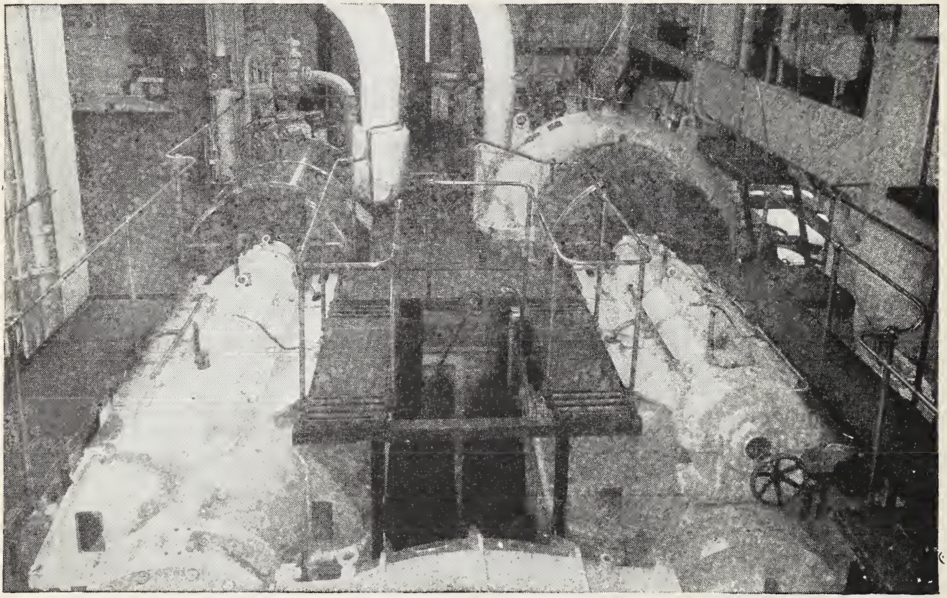


Fig. 31–6. The up-and-down motion of the knee is converted into circular motion by the bicycle crank and pedal.

Thus the modern steam engine operates quite differently from Newcomen's model. In the modern engine, the cylinder is maintained at a high temperature throughout the cycle of operation, whereas Newcomen's engine was alternately hot and cold. Why does this improve the efficiency of the engines?

Steam Turbines. Another engine for converting heat into work is the *steam turbine*. About two thousand years ago Hero of Alexandria made the first steam turbine with the device shown in Fig. 31–8. Water in the kettle was turned to steam which blew out of the arms and made the ball spin. It worked very much like the lawn sprinklers that rotate and throw a spray of water over the grass.

The old-fashioned water wheel is more like the modern turbine, and indeed a small model water wheel can be adapted to make a miniature turbine.



Courtesy General Electric Co.

Fig. 31–7. Two steam turbines supplying 6000 h.p. for the *Santa Rosa*. The high speed of the turbines is lowered by the large reducing gears in the foreground.

Demonstration 31–1. A Miniature Turbine.

A miniature turbine can be made from a small water wheel and an old-fashioned pressure cooker. Heat about a pint of water in the cooker until there is a pressure of about 15 pounds per square inch of steam inside. Be sure that the lid of the cooker is firmly in place, and clamp the parts as shown to reduce the danger of accidents and steam burns. Direct the steam through a small nozzle against the blade of the wheel, as shown in Fig. 31–9, and be careful to let the wheel come up to speed slowly. If it is well balanced, the wheel can be made to rotate at an amazingly high speed.

In a simple turbine high-pressure steam expands rapidly through a nozzle and pushes against cups on the edge of the wheel, thereby rotating it. A great deal of the steam, however, blows past the wheel and does no work, and even the useful steam bounces to one side of the cup without having spent all of its energy. A commercial turbine, like the section of the one shown in Fig. 31–10, is designed to catch the steam after it has pushed against one wheel and to make it push against the other wheels mounted on the same shaft. A series of fixed vanes set between these wheels and fixed to the outer case, deflects the steam so that it pushes against the second wheel in the same direction as it pushed against the first. A large turbine may have twenty or thirty moving wheels with fixed vanes between them.

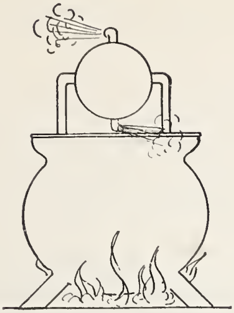


Fig. 31–8. Hero's steam engine, designed about two thousand years ago.

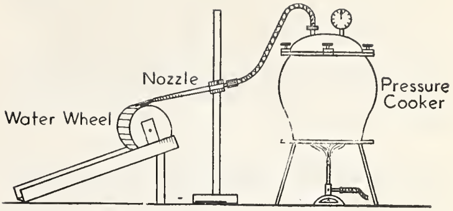
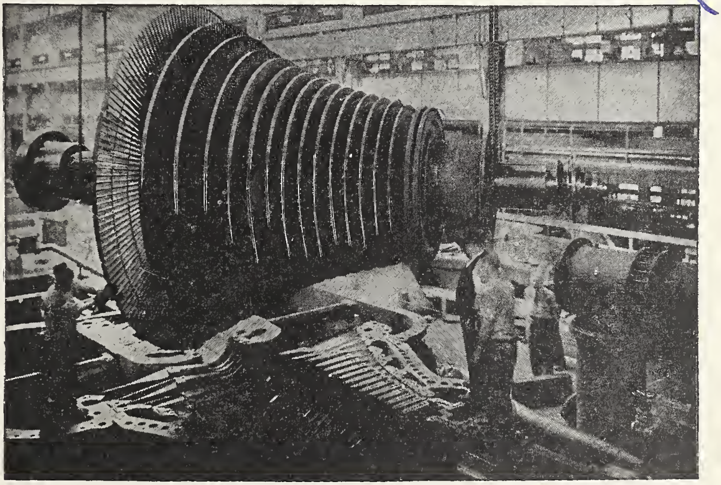


Fig. 31–9. High-pressure steam from a pressure cooker makes a miniature turbine spin at high speed.

Since the steam expands each time it pushes on the wheels, more and more space must be provided for it as it moves through the turbine. For this reason, turbines are small at the high-pressure end where the steam enters, and very large at the low-pressure end where it escapes. If all parts are properly designed, the steam will have spent its power by the time it escapes past the last wheel. A condenser is always connected to the exhaust to allow the steam to expand below atmospheric pressure. This not only increases the efficiency but also conserves water.

The turbines of a large ship like the *Queen Mary* use thousands of gallons of water every day. This water must be collected and used again after passing through the turbines; otherwise the ships could carry only enough water for a few days' journey. The exhaust steam from the turbines is therefore condensed to water which can be pumped back to the boilers.

One type of condenser looks somewhat like a fire-tube boiler except that cold water instead of fire runs through the tubes. Sea water is used for this purpose. Thus, although sea



Courtesy General Electric Co.

Fig. 31–10. The rotating member of a large modern turbine.

water, because of its many impurities in solution, cannot be used in the boilers, it provides an unlimited amount of condenser water. A condenser more than pays for itself by conserving fresh water and by increasing the efficiency of the engine.

Comparison of a Turbine and a Reciprocating Engine. Since the year 1900 turbines have almost completely displaced reciprocating steam engines in large power plants. They 1 have less vibration, 2 require only about one-tenth as much space, 3 and cost only one-third as much as a reciprocating engine of the same output. Because of their high constant speed they are 4 especially well adapated to driving electric generators. They are frequently used on ships because they are 5 more efficient than ordinary steam engines, and they also 6 help to stabilize the ship and reduce rolling. They have the disadvantages of not running efficiently at low speeds and of not being reversible. For these reasons large gears are used to reduce the speed to a proper value for a propeller and to reverse the engine.

The development of the various types of steam engines to their present-day efficiency entailed many difficulties over a long period of time. The steam engine really has a big job to do. It converts the stored-up energy of coal into energy of motion. This requires three separate steps: (1) the chemical process of combustion, in which the energy of a fuel is converted into heat; (2) the conversion of heat into the motion of a piston or of a turbine wheel; and (3), most difficult of all, the transfer of the motion of such engines into motion useful to man. The last step is illustrated by the motion of a locomotive or the motion of the parts of a complicated machine, as in a water pump for mines. We shall see in the next chapter that the same three steps are essential in the development of the internal-combustion engine.

THINGS TO REMEMBER

Engines convert the energy of fuel into mechanical work.

The *more work* an engine has to do, the *more steam* is required and the *more fuel* must be burned.

The *work done by a steam engine* comes directly from the expanding and cooling of steam.

Three steps are necessary in converting a fuel into useful work: (1) the chemical process of combustion; (2) the conversion of heat into the motion of a piston or of a turbine wheel, and (3) the transfer of this motion into motion useful to man.

The *reciprocating steam engine* has a piston that moves back and forth in a cylinder.

The *steam turbine* has a wheel that rotates at high speed.

In both types of engine a *condenser* conserves water and increases the efficiency of utilization of the fuel.

QUESTIONS

A

1. Name two sources of power used by man before the invention of the steam engine.
2. What are the two essential parts of a steam plant?
3. Is steam allowed to enter a steam cylinder during the whole stroke of the piston? Explain.
4. What is the function of the slide valve of a steam engine?
5. Why is a flywheel necessary on a single-acting steam engine?
6. How does the motion of a steam-turbine wheel differ from the motion of a steam-engine piston?
7. What is the advantage of a steam turbine over a reciprocating engine? (above)
8. Would a flywheel be needed on a steam turbine? Explain.
9. Why is sea water used in condensers on ships but not in the boilers?

B

10. Name two ways in which a condenser makes a steam turbine more efficient.

11. What are the three essential steps in converting the energy of coal into the energy of motion?

12. Draw a simple diagram of a water-tube boiler and tell how it operates.

13. Describe the cycle of operation of a double-acting steam engine.

14. Explain how a steam turbine operates.

15. Steam from the boilers enters the cylinders of a locomotive at a temperature of about 200° C. and leaves at about 100° C. Is a drop in the temperature of the steam necessary? Explain.

16. (*a*) Describe, with a diagram, the Newcomen engine.
(*b*) What was its main fault?

PROJECT

Visiting a Power Plant. Arrange to visit a nearby factory or electric generating plant that uses steam power. Examine the equipment with the engineer in charge. You should be able to tell whether a steam engine or a steam turbine is used. What kind of boiler is used? If it is a steam engine, can you find the throttle valve, the slide valve, the cylinder, the condenser, and the exhaust? If it is a turbine, can you point out which is the exhaust end? How fast is the turbine rotating? What is the nature of the work done by the engine? Write a report showing how the energy of the fuel is converted into work.

Make a simple diagram showing the arrangement of the various parts, labeling them carefully.

because its that drop in temperature that is enabling it to do its work. It is only as the heat is released that the energy is released.

Chapter 32

INTERNAL-COMBUSTION ENGINES

James Watt's steam engine greatly influenced world trade because it facilitated transportation. Why is the movement of goods and people from one place to another so important? The answer is that only by transportation can the peoples of the earth be assured of an adequate distribution of food and goods that are not native to their regions. The rich deposits in the earth are not distributed evenly among the peoples of the world. Some countries have rich coal deposits; others have oil; others, again, have iron ore; and some countries have none of these natural resources. Because climate varies considerably in different parts of the earth, in some regions wheat is grown in abundance, in others tropical fruits, in others cotton, and in still others cattle or sheep. It is not surprising, therefore, that engineers and scientists devote their attention and energy to the development of new and improved means of transporting products throughout the world.

The next major advance beyond the steam locomotive was the *internal-combustion engine.* As the name suggests, in an internal-combustion engine a fuel is burned *inside* the cylinder rather than outside, as it is in a steam engine. Also, in the internal-combustion engine sparks occur in rapid succession at suitable intervals to ignite the fuel-air mixture in the cylinder. A method of providing these sparks was not developed until the latter part of the 19th century.

The internal-combustion engine is now used to drive automobiles and trucks, to propel small boats, and to fly airplanes. But it is also used for other purposes. Isolated communities and farms, for example, use these engines to provide light and power to do mechanical work.

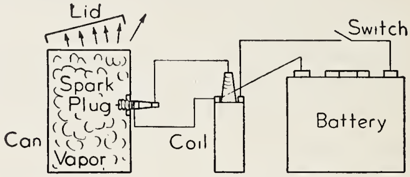


Fig. 32–1. When the switch is closed and then quickly opened, a spark will ignite the gasoline vapor in the can and blow off the lid.

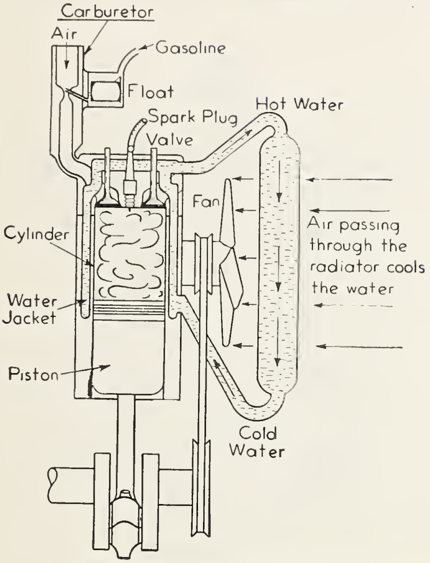
The two most common types of internal-combustion engine are the gasoline engine and the Diesel, or oil, engine.

The Four-Stroke Gasoline Engine. The most common internal-combustion engine burns a mixture of gasoline and air ignited by an electric spark. The following simple experiment shows that an explosive force is developed in this operation.

Demonstration 32–1. Burning an Air-Fuel Mixture.

Obtain a strong metal can with a friction lid. Into the side of it insert an automobile spark plug, as shown in Fig. 32–1. An automobile ignition coil will serve to produce a spark when connected to a 6-volt battery as shown. With an atomizer fill the can with vaporized gasoline. *Caution:* Gasoline vapor can be dangerous if not handled properly. *Do not squeeze the atomizer near an open flame.* Put the lid on the can, and ignite the mixture with a spark. It will explode and blow the lid off the can.

In the atomizer the liquid gasoline is broken into a spray of droplets and mixed well with the air. If this mixture is of proper proportions, it will ignite and burn rapidly when a spark is fired in it. The gases formed during the burning expand rapidly and produce the explosive force.



Based on a diagram from General Motors Corp.

Fig. 32–2. The essential parts of a gasoline engine: carburetor, valves, cylinder, piston, spark plug, and cooling system.

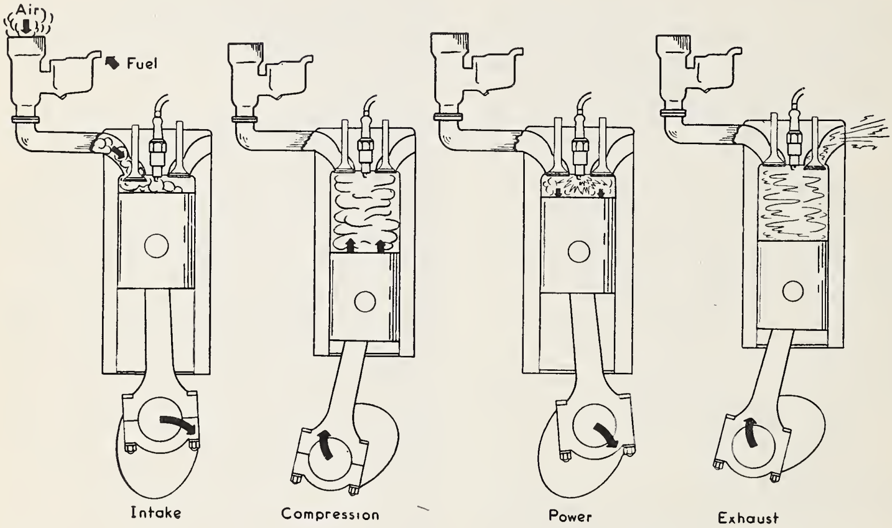
The same action occurs in the cylinder of an automobile engine. A single explosion will not, of course, drive a car very far or very fast. Many explosions per minute are needed to do this, and various drive shafts and gears must be used to transfer the force of the explosion to the wheels of the car. Automobile engineers have devised a simple, reliable mechanism for accomplishing all this easily and efficiently.

The Parts of the Engine. The fundamental parts of a gasoline engine are shown in Fig. 32–2. They are the carburetor, valves, cylinder, piston, spark plug, and cooling system; all are necessary for the proper operation of the engine. The carburetor mixes the liquid gasoline with air to form an explosive mixture. One valve controls the flow of this vapor to the cylinder. The spark plug ignites the vapor, which burns vigorously and pushes the piston down. Another valve lets out the exhaust gases. The water in the cooling system prevents the engine from getting too hot to function properly.

Study

The Operation of the Engine. The cycle of an engine can easily be followed in Fig. 32–3. First the piston moves down the cylinder, at the same time sucking the fuel mixture through the open intake valve. When the piston reaches the bottom of its stroke, the intake valve closes and the piston rises up the cylinder, thereby compressing the mixture. When the piston reaches the top of its stroke, a spark occurs at the spark plug which ignites the fuel, and the expanding gases drive the piston down in a so-called *power stroke*. Finally, the exhaust valve opens, and the piston rises to push the burned gases through it. The cycle is then repeated. *The whole operation consists of four strokes of the piston.* Three of these strokes are used to prepare the system for the single power stroke. For this reason it is called a four-stroke-cycle or, more simply, a *four-cycle engine.*

Most automobile engines consist of four, six, eight, twelve, or even sixteen cylinders like the one described above. Sometimes the cylinders are arranged in line, but for compactness they may be arranged in a V-shape, in a circle, or in other ways, as in Fig. 32–4. *Each cylinder goes through the cycle of intake, compression, power, and exhaust;* however, no two cylinders perform the same action at exactly the same time. In a four-cylinder engine, for instance, one cylinder takes in fuel, while another compresses fuel, another explodes fuel in its power stroke, and the fourth exhausts burned gases. This out-of-step arrangement allows for an explosion at every stroke and results in a smoother flow of power from the engine. When an engine is to be started, it must be turned over several times to get fuel into the cylinders. This was done by hand until C. F. Kettering devised the electric starter, an electric motor driven by a storage battery, which is used today.



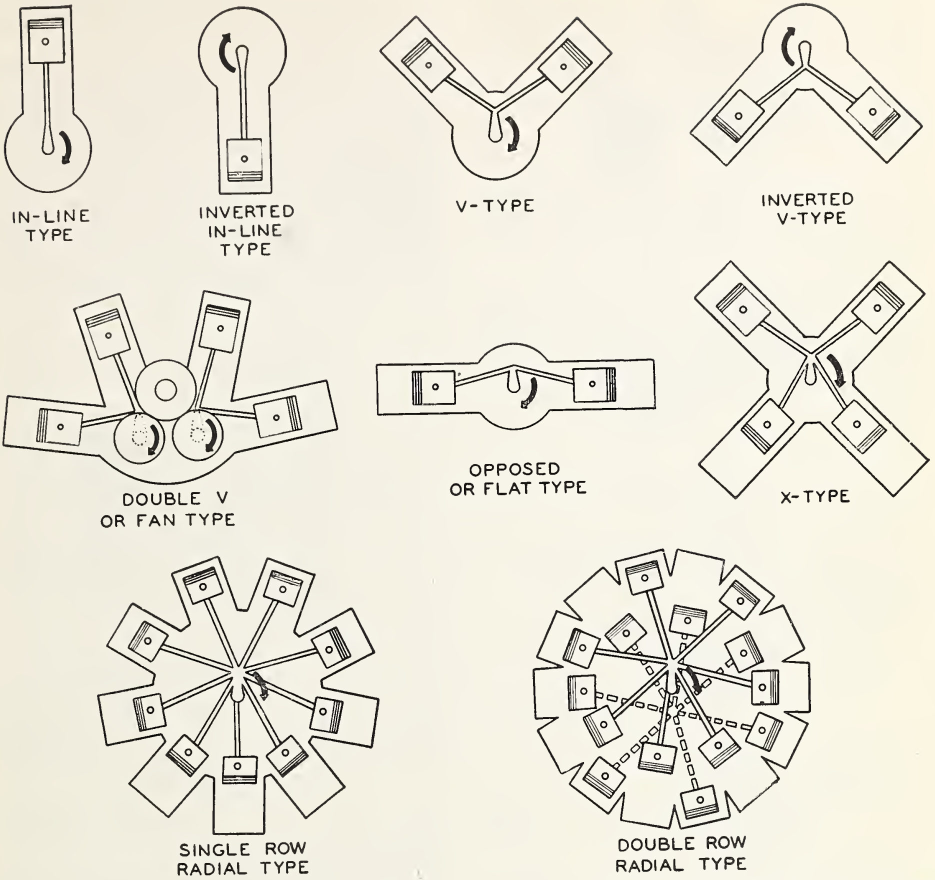
Based on a diagram from General Motors Corp.

Fig. 32–3. The four strokes of a four-stroke-cycle engine are intake, compression, power, and exhaust.

The Power System of an Automobile. Once the engine has been started, the motion of the pistons is transferred to the wheels of the automobile through a series of rods, shafts, and gears. A *connecting rod* connects the piston with the *crank* on a *crankshaft*, thereby changing the up-and-down motion of the piston into the rotary motion of the crankshaft. The *flywheel* on the crankshaft keeps the engine spinning smoothly between power strokes.

A *clutch* on the back of the flywheel disconnects the engine from the wheels of the car when the driver pushes down on the clutch pedal. In other words, the clutch allows the engine to continue running while the automobile remains stationary or coasts. There are also various types of automatic transmissions that may replace the clutch. The *gears* in the transmission change the speed at which the engine drives the car. In low gear, for instance, a small gear on the motor drives a larger gear connected to the rear wheels. The large gear moves more slowly than the small one because there are more teeth around the circumference of the large gear. This enables the engine to develop more force for starting the car and pulling heavy loads. A *drive shaft* carries the power to the rear wheels, which make the car move. what is lost in speed is gained in force

The power needed to drive a car varies

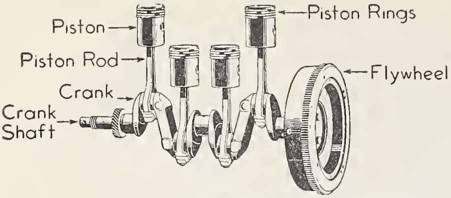


Based on a diagram from General Motors Corp.

Fig. 32–4. The cylinders of engines may be arranged in various ways. The way in which they are arranged depends on the space available, cooling requirements, streamlining, or other factors.

with the speed of the car and the slope of the road. A *throttle* or *accelerator pedal* governs the rate at which fuel is fed to the motor, thus regulating the power under varying conditions.

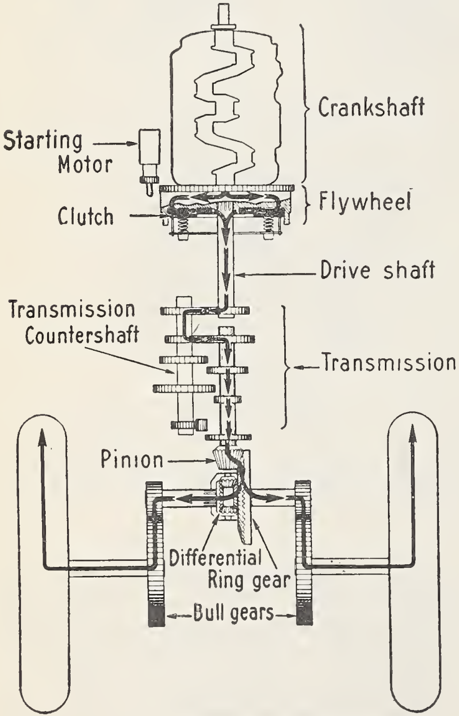
Control of Gasoline and Air. Oddly enough, a gasoline engine consumes much more air than gasoline. For every gallon of gasoline used, the engine requires 1200 cubic feet, or 8300 gallons, of air, enough to fill a room 12 feet long, 10 feet wide, and 10 feet deep. The *carburetor,* shown in detail in Fig. 32–7, mixes the fuel and air in a fine spray that burns rapidly when ignited. A simple carburetor contains a float that moves a *needle valve* to govern the level of the gasoline in the nozzle or *jet.* Air rushing past the jet



Courtesy International Harvester Co.

Fig. 32–5. The up-and-down motion of the piston is changed to circular motion of the crankshaft.

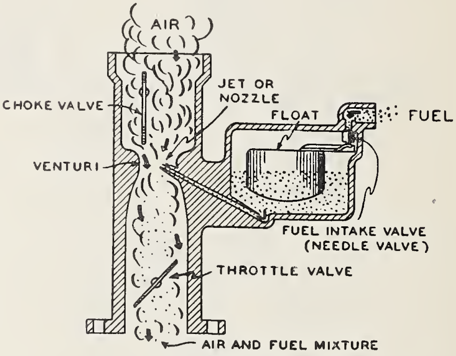
carries some gasoline with it, the total flow being governed by the throttle valve. A *choke* can be closed to reduce the amount of air that mixes with the gasoline and provide a richer mixture for starting on a cold morning. Most cars now have an automatic choke.



Courtesy International Harvester Co.

Fig. 32–6. Power is transferred from the engine to the rear wheels by a series of devices which make for easy control of this tractor.

Exploding the Mixture. After the fuel enters the cylinder, it is compressed to about one-seventh of its original volume. Three or four *piston rings*, shown in Fig. 32–5, are used to prevent the escape of the highly compressed gases from the cylinder. If an engine has poor compression because of worn piston rings or cylinder walls, some of the fuel mixture will leak past the piston rings and be lost. This results in low mileage and poor operation of the engine.



Courtesy General Motors Corp.

Fig. 32–7. The carburetor mixes air and gasoline for the engine. This is a down-draft carburetor with the throttle partly closed.

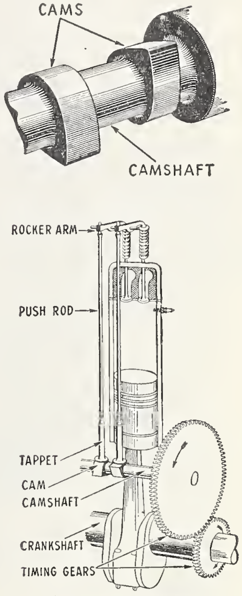
When the gas has been compressed, a spark is made to jump across the *spark plug*, forming a small high-temperature region in which the gases ignite and burn. The temperature of the exploding mixture may reach 4500° F., which is higher than the melting point of steel. For this reason, water is circulated in a *water jacket* around the cylinder and valves to keep them cool. The warm water rises to the top of the engine and flows into the radiator at the front. Air, driven through the radiator by the motion of the car and by the fan, cools the water, which then re-enters the engine at the bottom. The natural convection of the water in this circulating system is usually aided by a small *water pump*.

Lubrication. Lubrication of the moving parts of the engine is essential. Otherwise heat due to friction will develop in the bearings and in the cylinders, where the tightly fitting pistons rub back and forth. The *crankcase*, which covers the bottom of the engine, contains oil for the lubrication of the engine. Oil from the crankcase is forced through vents and pipes to all possible friction points in the motor. Some of the piston rings, for instance, spread oil over the surface of the cylinder wall and thereby reduce the wearing of the cylinders.

In an engine of several cylinders, some parts may serve all cylinders. For instance, only one carburetor is needed, the mixture being fed to all the cylinders through an *intake manifold*. (A *manifold* is a pipe with many inlets or outlets, one for each cylinder.) Similarly, only one exhaust is needed, the exhaust from each cylinder being fed through an *exhaust manifold* to the main exhaust pipe. The operation of the intake and exhaust valves of each cylinder is provided for by a single *camshaft*, or rod which runs through the whole engine. On the rod are *cams*—off-center devices—which, as they rotate, raise and lower the valves at the proper time. A single ignition system supplies the spark for all cylinders, a distributor or rotating arm making the connection to the proper cylinder at the right time.

Gasoline engines have one serious disadvantage. The fuel which they use is highly inflammable and is therefore a source of danger. Gasoline vapor may be ignited by careless smokers, by sparks, or in a collision. Such fires spread quickly and are difficult to extinguish. As a precaution a suitable fire extinguisher should always be kept near a gasoline engine.

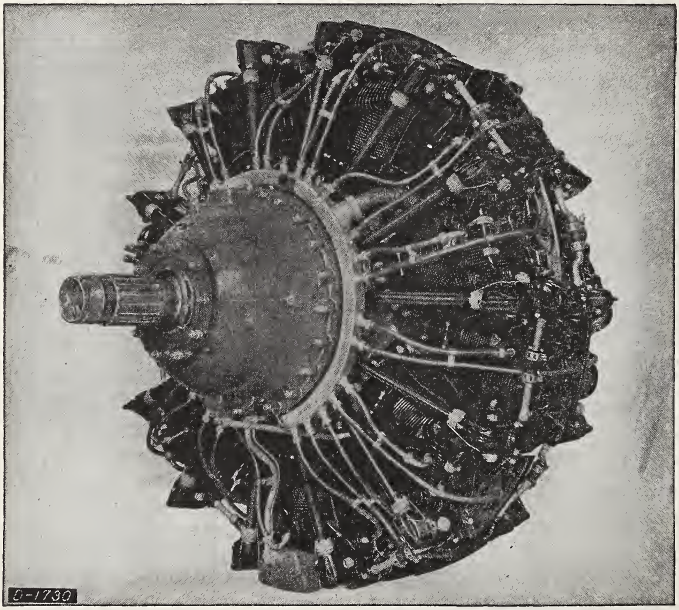
The Airplane Engine. Although the gasoline engine was designed for automobiles, it was readily adapted for use in airplanes. Some changes were necessary, however. The engine had to be built as light as possible with no sacrifice in power. Some engines were made in radial form, as in Fig. 32–9, as they could be easily air-cooled. The engine was fitted with superchargers to enable it to operate efficiently at high altitudes where the air is thin. Chemists developed more powerful fuels for use in the airplane engine, and engineers solved the problem of keeping it operating in temperatures far below 0° C. But with all these refinements, the engine had to use gasoline for fuel.



Courtesy International Harvester Co.

Fig. 32–8. The cams, which are driven by the engine through timing gears, open and close the valves at the correct moment.

The Diesel Engine. The internal-combustion engine depends on gasoline for its fuel. But gasoline is expensive, and the supply is limited. An internal-combustion engine that burns oil not usable by a gasoline engine was developed by a German engineer, Rudolf Diesel. The *Diesel engine* resembles the gasoline engine, but it has no carburetor; only pure air is drawn into the cylinder. The piston then compresses this air to one-eighteenth of its original volume. This high compression raises the temperature of the air to about 1000° F. When the piston is near the top of its stroke, a fine spray of oil is injected into the cylinder by a pump. The oil burns instantly in the hot compressed air, and the hot gases force the piston down the cylinder as in the power stroke of the gasoline engine.



Courtesy United Aircraft Co.

Fig. 32–9. A 1,200-horsepower air-cooled airplane engine.

The pressures developed in the cylinder by the explosions are as high as 1,000 pounds per square inch, and the walls of the cylinder must be strong and heavy enough to withstand this high pressure. Thus a big Diesel may weigh 250 pounds for each horsepower it develops, whereas a comparable gasoline engine weighs only 10 or 15 pounds per horsepower. The Diesel has therefore not displaced the gasoline engine because of its weight. In aviation Diesels the weight has been reduced to about 5 pounds per horsepower, but the aviation gasoline engine weighs less than a pound per horsepower. In the air this difference in weight is of major importance, because the heavier the engine the less the payload the plane can carry. However, active research in the new lighter alloys for airplane construction and in improved design may make the Diesel an important competitor of the gasoline engine in aviation. In spite of their disadvantageous weight, Diesels are becoming increasingly popular in ships, trains, trucks, tractors, and small electric generator plants.

The Two-Cycle Diesel. Another form of Diesel engine (see Fig. 32–11) supplies the

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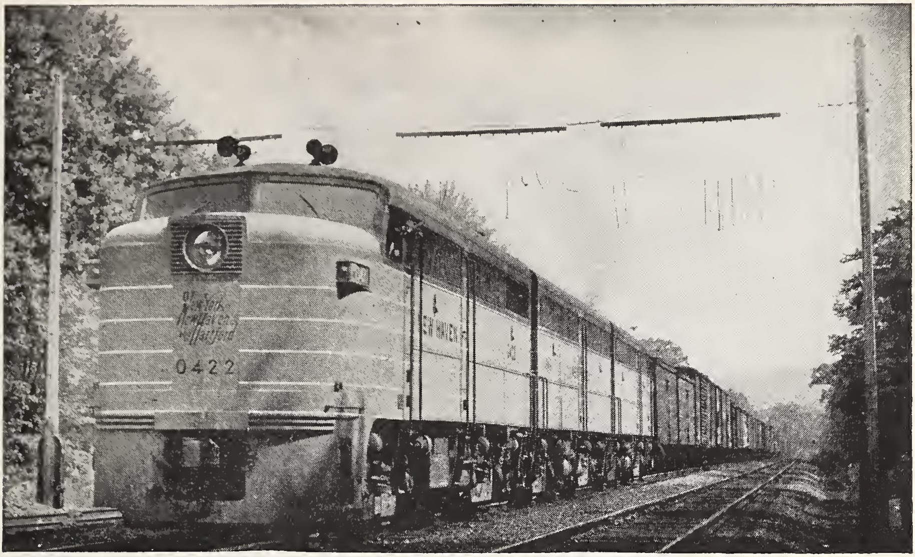
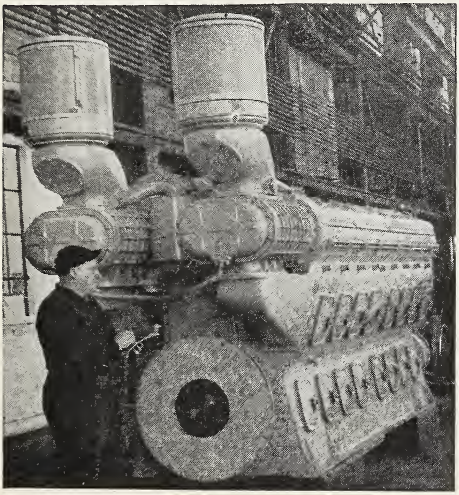


Courtesy The New Haven Railroad

Fig. 32–10. This Diesel-powered locomotive hauls freight rapidly and economically. The Diesel engine in the locomotive drives an electric generator, which in turn runs electric motors built on the axles of the train.



Courtesy Boston and Maine Railroad

Fig. 32–11. A two-cycle Diesel engine capable of delivering 1,350 h.p. Two of these engines are used in each section of a Diesel locomotive.

power in streamlined Diesel-electric locomotives. In this type two of the four strokes of the standard engine are eliminated. The explosion occurs as usual when oil is injected into compressed air. But when the piston reaches the bottom of its stroke, compressed air is blown by an auxiliary pump through holes in the cylinder wall. This drives the burned gases out through the exhaust valve and fills the cylinder with clean air which is then compressed by the rising piston. At the top of the compression stroke oil is injected, and the action repeats itself. Thus power is delivered on every down-stroke of the engine. It is therefore called a two-stroke-cycle engine.

Small model airplane motors and outboard motors for boats are usually two-cycle motors. The two-cycle Diesel is less efficient than the four-cycle one because it uses more fuel for the power produced, but it delivers more horsepower per pound of weight. It is probable, therefore, that most of the experimental Diesels for use in airplanes will be of the two-cycle type.

THINGS TO REMEMBER

Internal-combustion engines burn fuel inside the engine rather than outside. There are two common types: the gasoline engine and the Diesel engine.

All internal-combustion engines require *fuel, air,* and a *method of igniting the fuel.*

In a *gasoline engine,* an electric spark ignites the fuel mixture.

In a *Diesel engine,* hot compressed air ignites the fuel.

Most internal-combustion engines operate on a *four-stroke cycle:* intake, compression, explosion, and exhaustion. power

QUESTIONS

A

✓1. What three things do internal-combustion engines need for their operation?

✓2. Name the six fundamental parts of a gasoline engine.

✓3. What two types of internal-combustion engine are in common use today?

✓4. Name the four strokes of a four-cycle engine.

✓5. What is the purpose of a carburetor?

✓6. What keeps an automobile engine from overheating?

7. What is a Diesel engine?

8. What is the purpose of the injector pump of a Diesel?

9. What is a two-cycle engine?

10. State one advantage and one disadvantage of a two-cycle engine.

11. What is the chief difference between internal-combustion engines and steam engines?

12. What special construction in an automobile radiator helps to cool the water that passes through it?

13. When must the firing of the spark occur in relation to the movement of the piston of a gasoline motor?

14. Name two ways in which a Diesel engine differs from a gasoline engine.

B

15. Describe the sequence of operations of a four-cycle gasoline engine.

16. How does the up-and-down motion of a piston become rotary motion?

17. Why is the compression ratio of a Diesel very high?

18. Why must a Diesel be more ruggedly built than a gasoline engine?

19. How does the two-cycle Diesel eliminate two of the normal strokes of an engine?

20. Why are Diesels less suitable than gasoline engines in airplanes? Explain.

PROJECTS

1. *To Analyze an Automobile Engine.* Obtain an old automobile engine from a local garage or junkyard. Remove it to a convenient place, such as the basement of the school. Clean it carefully with kerosene and then take it apart. List the parts as you remove them, making simple sketches to show their position in the engine.

   Finally cut away parts of the engine, such as one cylinder wall, the sides of the transmission, and the cover of the drive shaft. Mount the whole engine on a heavy wooden base as a permanent working exhibit for the school.

2. *Examining an Airplane Engine.* Show that a small model airplane engine works as a two-cycle engine. Draw a diagram of a cross-section of the cylinder to show where the fuel and air enter and leave the engine.

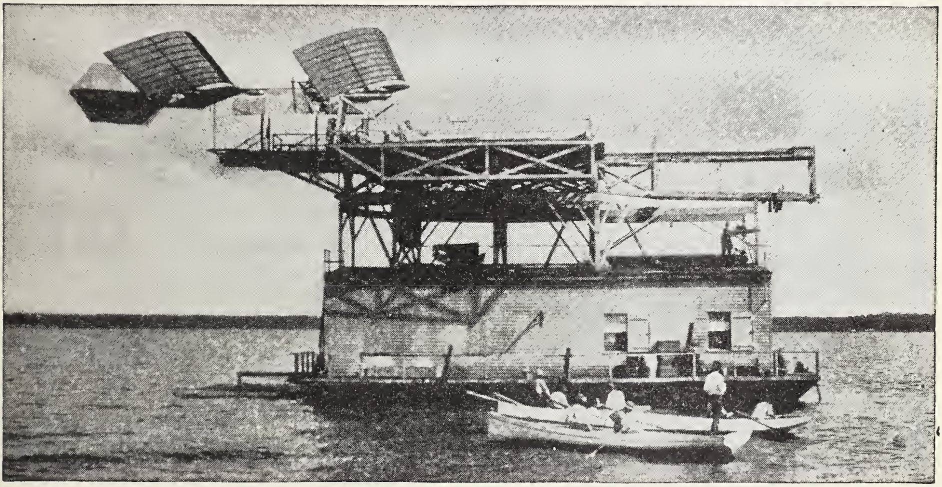
Chapter 33

THE AIRPLANE

Aviation was born about fifty years ago when two young brothers, Wilbur and Orville Wright, launched themselves in a glider from the steep sides of sand dunes at Kitty Hawk on the coast of North Carolina. Their preliminary experiments in flying occupied twelve years. During this time they built an engine and a propeller for a plane which they had designed and constructed themselves.

In 1903 they were ready for their first attempt to fly with power. The brothers flipped a coin to decide who should be the first to try the new flying machine. Wilbur won. He lay flat on the lower wing of the biplane and started the engine. After a short run the machine rose, but it remained in the air only three seconds.

A few days later, on December 17, 1903, the test was repeated with Orville on the wing. This time the plane rose about 10 feet, covering 120 feet in 12 seconds before it dived to earth. Then it was Wilbur's turn. When the plane was released Orville ran alongside holding one wing of the plane to steady the craft



Courtesy Air Museum, Smithsonian Institution

Fig. 33–1. Samuel P. Langley's airplane, *Aerdrome A*, on a houseboat in the Potomac. The plane successfully flew for about a half mile in 1896, but it did not carry anyone aloft.

until it left the ground. This time Wilbur flew for 59 seconds, covering a distance of 852 feet.

The brothers were flying into a 27-mile-an-hour wind, and it is estimated that these first flights were made at about 33 miles an hour. Although it is difficult to separate the achievements of the brothers, Orville is usually given the distinction of making the first sustained flight in a heavier-than-air machine.

Wilbur died in 1912, but Orville lived to see their flimsy contrivance develop into giant airliners. In fifty years, the airplane has revolutionized world transportation.

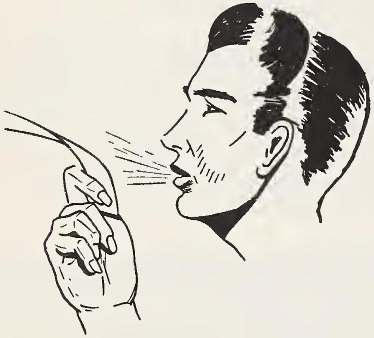


Fig. 33–2. A stream of air will lift the end of a strip of paper because of the Bernoulli effect.

What Makes an Airplane Fly? Balloons and dirigibles rise and are supported in the air because of the buoyant force exerted by the air they displace, as described in Chapter 7. Heavier-than-air machines, such as airplanes and helicopters, depend on a different force to support them. This force is produced by the rush of air over the wings of the plane. Similar forces can be demonstrated with a piece of paper.

Demonstration 33–1. Lifting Effect of an Airstream.

Cut a piece of paper about 2 inches wide and 10 inches long. Hold it vertically in front of your face. Drop the top edge away from you so that the paper folds over your hand. Then blow smoothly across the top surface of the paper as shown in Fig. 33–2. The paper rises into the airstream and flutters there instead of being blown down.

Apparently a *lifting effect* is produced by the airstream sufficient to hold up the piece of paper. A similar effect, on a larger scale, holds up an airplane. This is often referred to as the Bernoulli lift.

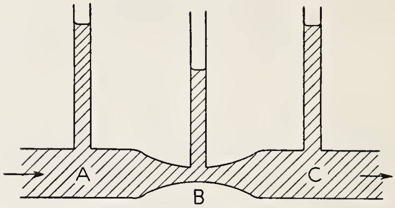


Fig. 33–3. Drop in pressure in a constriction because of Bernoulli effect.

The Bernoulli Effect. In Chapter 7 we saw that as a liquid flows through a pipe the pressure drops gradually because of the internal friction. An even more conspicuous drop in pressure occurs as a liquid or gas flows through a constriction, or narrow part of a tube or pipe. This is known as the *Bernoulli effect.* It can be shown in the following demonstration.

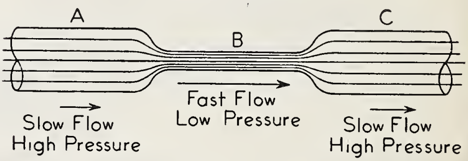


Fig. 33–4. Wherever a liquid or gas is made to flow faster, the pressure becomes lower.

Demonstration 33–2. Drop in Pressure in a Constriction.

Fig. 33–3 shows a tube with inlets at *A*, *B*, and *C*, and a constriction at *B*. The height of the water in the inlet tubes indicates the pressures at A, B, and C. When water flows through the main tube, the level in the tube at *B* is lower than the levels in the tubes at A and C.

How can we account for the lower pressure at *B*? The water flows to the right. As it flows through the constriction at *B*, it passes through a much smaller cross-section area than it does at *A*. It must therefore travel much faster at *B*. To speed up the flow, the pressure behind it must be greater. That is, the pressure at *A* is greater than the pressure at *B*. As the water also flows more slowly at *C* than at *B*, the pressure at *C* must be greater in order to slow down the water.

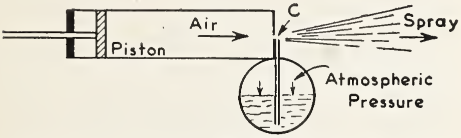


Fig. 33–5. An insect sprayer makes use of the Bernoulli effect to produce a spray of fine droplets.

Examples of the Bernoulli Effect. Actually, if the pressure in the constriction becomes lower than atmospheric pressure, a partial vacuum is produced. The insect sprayer shown in Fig. 33–5 uses such an effect. When the air in the tube is pushed out suddenly through the constriction *C* in the end of the tube, the pressure there is so greatly reduced that the atmospheric pressure in the reservoir drives liquid up the tube to the air stream. The liquid is then broken into droplets and mixed with the air to form a fine spray.

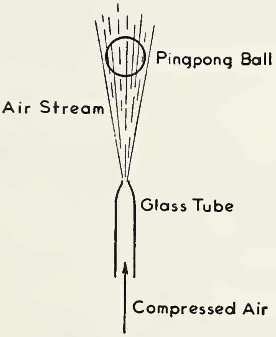


Fig. 33–6. Atmospheric pressure is greater than the pressure in the air stream, thereby supporting the ball beneath the stream.

A strong wind blowing over the top of a chimney may produce the same effect, increasing the draft on the fire. And Ping-pong balls can be made to float in an air stream from a small nozzle, as in Fig. 33-6. The air in the center of the stream has a greater velocity, and therefore a lower pressure, than that on the outside. As a result, atmospheric pressure forces the Ping-pong ball toward the region of low pressure.

Demonstration 33–3. The Bernoulli Effect in Air.

Stick a pin through a small piece of cardboard and let the pin project upward into the hole of a wooden spool, as shown in Fig. 33–7. Holding the card near the spool, blow through the hole. While continuing to blow, remove your hand from the card. Notice that the card is not blown away from the spool but, instead, is held in place by the pressure from below.

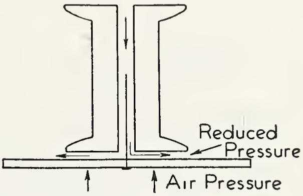


Fig. 33–7. The Bernoulli effect in air.

The high velocity of the escaping air causes a reduced downward pressure on the card. Therefore the upward pressure on the bottom of the card is greater and prevents the card from falling.

Forces on an Airplane Wing. A similar effect takes place as air flows over the wing of an airplane. The wings of modern airplanes are made in the shape shown in Fig. 33–8. As air rushes past the wing, the air that passes over the top has to go farther than that passing underneath. This results in increased velocity and reduced pressure on top of the wing. The arrows show the direction and the amount of reduction in pressure, the total effect being shown by the heavy arrow *BF*.

The air blowing on the underside of the wing produces some upward force, but most of the lifting effect is due to the reduced pressure above the wing. The shape of the wing is very important. In fact, a coating of ice on a wing may change the shape of the wing enough to reduce the lifting force to the danger point. De-icing equipment, like the rubber edge of the wing (see Fig. 33–9), is used to reduce this hazard. An air pump inflates the edge of the wing with a pulsing motion that breaks off the ice as it forms, thereby keeping the wing shape correct.

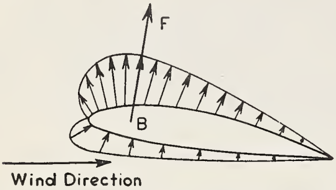


Fig. 33–8. Forces on an airplane wing are produced by reduction of pressure above the wing and a small application of pressure below the wing.

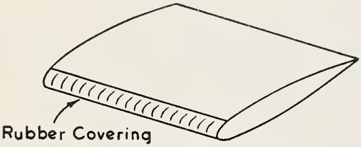


Fig. 33–9. The leading edge of the wing has a rubber covering which can be inflated by an air pump to loosen ice, which then blows away.

A Study of Forces. The force *BF*, in Fig. 33–8, produced by the air on the wing, is what holds the plane up; that is, it provides the *lift*, which equals the *weight* of the plane. Notice, however, that the force *BF* is tilted backward, whereas the lift and weight act vertically. Apparently the force *BF* is doing two things at once. It is, to some extent, holding the plane up by causing the lift; and it is also, to some extent, holding the plane back, or producing what is called *drag*. Drag is due to the friction of the air as it goes by the wing.

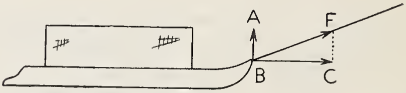


Fig. 33–10. The force *BF* on the sled rope has components *BC*, acting horizontally, and *BA*, acting vertically.

Components of a Force. If we divide the action of a single force into two or more other forces, as we did above, we say that we have produced *components* of the original force. On the airplane wing (Fig. 33–8) the components of the force *BF* are the lift and the drag. On the sled shown in Fig. 33–10 the force along the rope has two components. One component drags the sled on the ground, and the other tends to lift it. In Fig. 33–11 the force exerted by the man on the lawnmower handle has one component which pushes the lawnmower along the ground and another component which pushes it perpendicular to the ground. You should be able to figure out the usefulness of each of these components.

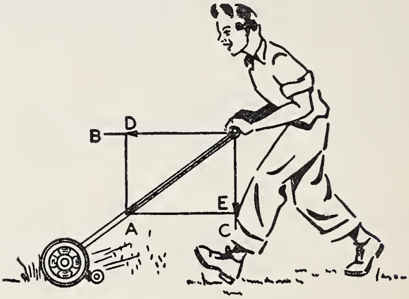
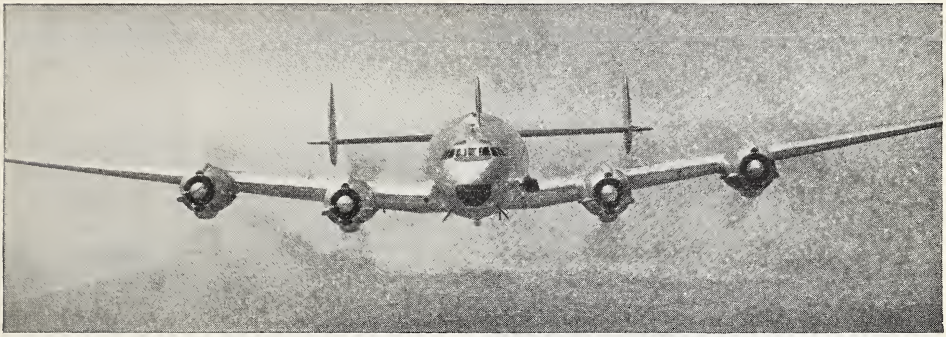


Fig. 33–11. Resolution of forces into components along the ground and perpendicular to the ground.

Drag and Thrust. On the airplane wing the drag is a force that tends to slow the plane down. If the plane is to remain in flight, the drag must be matched by the thrust of the propeller. Actually, all the surfaces of the airplane contribute to the total drag which the thrust of the propeller must counteract.

If the motor is speeded up, the thrust becomes, for a moment, greater than the drag, and the speed of the plane increases. At the same time the greater flow of wind past the plane increases the drag, which eventually equals the higher thrust. Then the plane flies steadily at the higher speed. Slowing down the motor produces the reverse effect; that is, the thrust is less than the drag, and the plane slows down.

Streamlining. The motor of a plane must exert force enough to overcome the drag, and any means of reducing the drag and yet producing satisfactory lift in the wing is valuable. Experiments show that a long, thin shape produces the least drag, so the body and wings of a plane are constructed in this manner. The design is known as *streamlining*. Similar streamlining is used on automobiles, but this is mostly for appearance because the effects of streamlining are not very great at speeds of less than fifty miles an hour.



Courtesy Lockheed Aircraft Corp.

Fig. 33–12. The thin, smooth, streamlined shape of a Constellation reduces the wind resistance or drag.

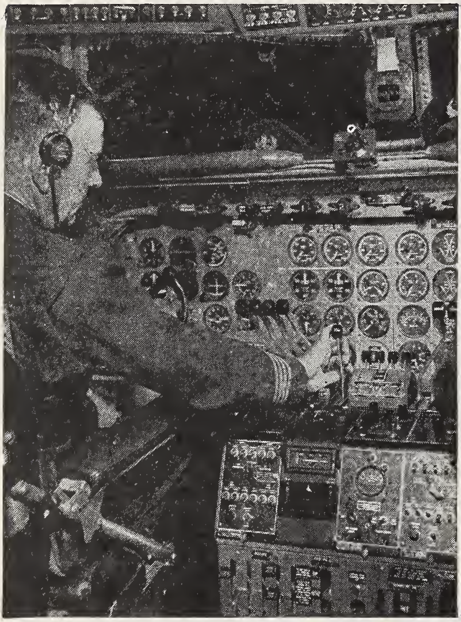
CONTROLLING THE PLANE

Motion of a Plane. The driver of an automobile must be capable of guiding his car along a road, slowing it down and speeding it up at the proper time, and stopping it when necessary. Most of the drivers who do this satisfactorily probably have no basic knowledge of what they are doing when they control their car. But an airplane pilot must understand the operation of his plane for the sake of his own safety and that of others. An airplane moves about more freely than a car, and improper operation of its controls might easily cause serious trouble.

An airplane must move forward, and it may move to the right or left, and up or down. It may move in two or three of these directions at the same time. It may speed up or slow down, climb or glide, bank right or left. All these motions are controlled by four devices: the *throttle* for the engine, the *elevators* for climbing or gliding, and the *ailerons* and *rudder* for turning.

The Throttle. The amount of gasoline fed to the engine is controlled by a throttle valve, shown in a typical pilot's cockpit in Fig. 33–13. Since an airplane is completely dependent on the power of its engine to stay aloft, the throttle and all other engine parts must work perfectly. Good pilots test the engine before every flight. If you make a flight, watch for this test.

When a plane takes off from the ground and starts to climb, it needs more power than it does for level, steady flying. During take-off, the plane is accelerating and climbing, both of which actions require extra power. When it is climbing, it must lift itself. When the plane is flying level, on the other hand, the engine has only to overcome the drag of air on the body and wings. Therefore, for take-off and climb the throttle valve is opened wide, whereas for level flight it is usually closed somewhat.



Courtesy American Airlines

Fig. 33–13. Cockpit of a DC–6 Airliner, showing the control wheel on the left, the throttles for the four engines in the center, and some of the other instruments on which the pilot depends for safety in flight.

When an airplane is in level flight, the lift on the wings equals the weight of the plane, and the drag on the wings and body equals the thrust of the engine. Opening the throttle of the engine increases the thrust, which is then greater than the drag, and the plane speeds up. But as the plane goes faster, the air rushes over the top of the wing more rapidly than before, increasing the Bernoulli effect to a value greater than the weight of the plane. The airplane therefore climbs at the same time that it speeds up. The reverse action occurs when the plane slows down; that is, the plane goes into a slow glide.

The Elevators. The usual way to make a plane climb or glide is to tilt the *elevators* on the tail of the plane. Fig. 33–14 shows the horizontal *stabilizer*, which is the small fixed wing on the tail of the plane, and the elevators, which are just behind the stabilizer. When the pilot pulls back on the control stick or wheel, the elevators tilt upward. The flow of air past them pushes the tail down, thus raising the nose of the plane, and the plane begins to climb. When the desired angle of climb is attained, the pilot returns the wheel to its normal position, but the plane continues to climb. To level off, he pushes the wheel forward, depressing the elevators and raising the tail. When the plane becomes level, he returns the wheel to its normal position.

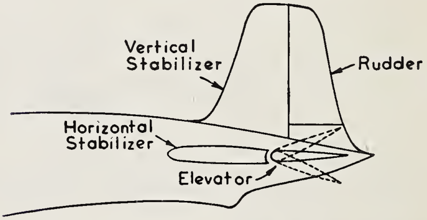


Fig. 33–14. The horizontal stabilizer and elevator of an airplane control the climb and descent. The vertical stabilizer and rudder control the direction of flight.

If the climb is not rapid, it is not necessary to increase the thrust; but if the climb is rapid, the throttle must be opened. Most of the increased lift, however, results from the change in the *angle of attack,* that is, the angle between the air stream and the wings. Various positions of the wings are shown in Fig. 33–15.

When the pilot wants to dive, he pushes his control wheel forward for a moment and generally closes the throttle somewhat. The plane will fly in a shallow dive until the pilot changes the elevators again.

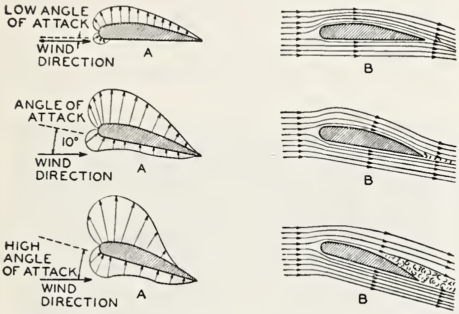
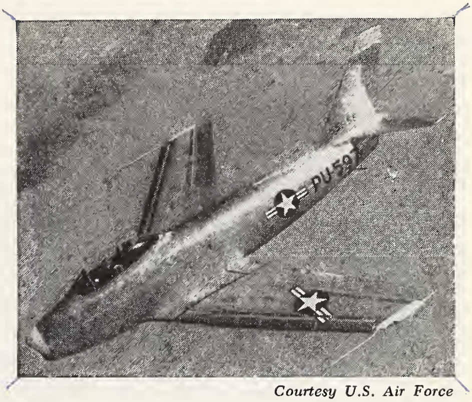


Fig. 33–15. The forces on an airplane wing vary with the angle of attack. The *A* figures show the forces on the wing, the *B* figures show the movement of air past the wing. When the angle of attack is more than about 10 degrees, the air flow becomes turbulent and the lift decreases.

The Ailerons and Rudder. Changing the direction in which a plane is flying is more complicated than making it climb or glide. The *rudder,* a vertical fin on the tail, can be turned, but this merely twists the plane so that it seems to skid sidewise in the direction in which it was moving before. In addition, a force must be produced to move the plane to one side. This is done by tilting the plane by means of *ailerons,* the movable sections of the trailing edge of the wing (see Fig. 33–16). Then if the elevator is raised slightly, the wings push sideways against the air and the plane changes direction. The ailerons are moved by the control wheel in the same way as the steering wheel of a car is used. Turning the wheel clockwise raises the aileron on the right wing and lowers the one on the left. This operation produces a right bank. Turning the wheel counterclockwise moves the ailerons the opposite way and produces a left bank.

The rudder is controlled by a *rudder bar* on which the pilot pushes with his feet. If the plane is to go to the right, the pilot pushes his right foot forward; if it is to go to the left, he uses his left foot. These actions are the opposite of those used in steering a sled.



Courtesy U.S. Air Force

Fig. 33–16. Ailerons are movable sections of the trailing edge of a wing. When one aileron tips up the other goes down.

Airplane Instruments. A pilot depends on special instruments in navigating his plane. All planes are equipped with at least four such instruments—a magnetic compass, an altimeter, a tachometer, and a clock. Commercial and military planes have many additional instruments.

Contact Flying. The direction in which a plane is flying can be determined if the pilot has a map and can see the ground. If he can identify objects both on the map and on the ground, he can fly from one object to the next. This is called *contact flying.* Railroad lines, rivers, and roads are common landmarks used for contact flying.

The Magnetic Compass. When the pilot flies through clouds or at night, he must often depend on a *compass*. By comparing the compass reading with the compass direction on a map, the pilot can tell where he is heading.

No compass is completely reliable, and a strong wind may blow a plane off its course. Commercial and military planes as well as many private ones now depend on radio beams for accurate information on the path of their flights.

The Altimeter. A pilot must always know how high above sea level his plane is, especially if he is flying in mountainous country. He finds this information on an *altimeter*. The altimeter in general use is essentially an aneroid barometer, described in Chapter 20, with the scale marked in feet instead of pressure units. It indicates height by showing the decrease in atmospheric pressure above sea level. But air pressure also varies with the weather. Pilots therefore depend on radio to supply them with information to correct the reading of their altimeters. Many planes, especially commercial airliners, use a *terrain clearance indicator*, a more complicated instrument that tells how far the plane is above any obstruction. Another means of locating an obstruction is by radar, which is discussed in Chapter 47.

The Tachometer. Proper engine speed is of prime importance in the operation of a plane. This information is given by the *tachometer*. There are several types of tachometer. One type consists of a small electric generator attached to the engine. The electricity produced by the generator depends on the speed of the engine. The electricity operates a dial on the instrument panel of the plane.

The Clock. A good pilot always plans his flight before leaving the ground. He predicts the time at which he will reach definite points along his journey. At frequent intervals during the flight he checks his predictions with the actual time. If he finds that he is far behind his schedule, because of head winds or engine trouble, he may have to revise his flight plan. Accurate clocks are especially necessary on long flights, or on flights in cloudy weather, when the engine speed, compass heading, and clock must tell the pilot where he is at any given moment.

THINGS TO REMEMBER

The Wright brothers were the first to fly in a *powered heavier-than-air machine* at Kitty Hawk, North Carolina, in 1903.

If the speed is great enough, the pressure of a gas or liquid is lowered where it flows through a constriction. This is the *Bernoulli effect*.

An airplane is lifted largely because the pressure on the upper surface of the wing is lower than that on the under surface. This is an example of Bernoulli lift.

A force may produce two effects at the same time in different directions. These effects are called *components* of the original force.

The two components on an airplane wing are called the *lift* and the *drag*.

To keep a plane in normal steady flight (*a*) the *lift* must equal the *weight of the plane*, and (*b*) the *drag* must equal the *thrust of the propeller*.

The motions of an airplane are controlled by its *throttle*, *elevator*, *ailerons*, and *rudder*.

An airplane must have on its instrument panel the following: a *magnetic compass*, an *altimeter*, a *tachometer*, and a *clock*.

QUESTIONS

A

1. What effect is largely responsible for the lift of an airplane wing?

2. What are the components of a force?

3. What is the vertical component of the force on an airplane wing? the horizontal component?

4. In level, steady flight, why must the lift on the wing only equal the weight of a plane, not exceed it?

5. Name the conditions that determine the amount of lift on the wing.

6. How is a plane made to climb?

7. What instruments are required on the instrument panel of a plane?

8. What is a tachometer?

B

9. Give a simple explanation of the Bernoulli effect.

10. What happens to the drag on a plane when the motor is speeded up?

11. If the average lift of the air on a wing is 2 pounds per square inch, what weight could be lifted by such a wing whose area is 120 square feet?

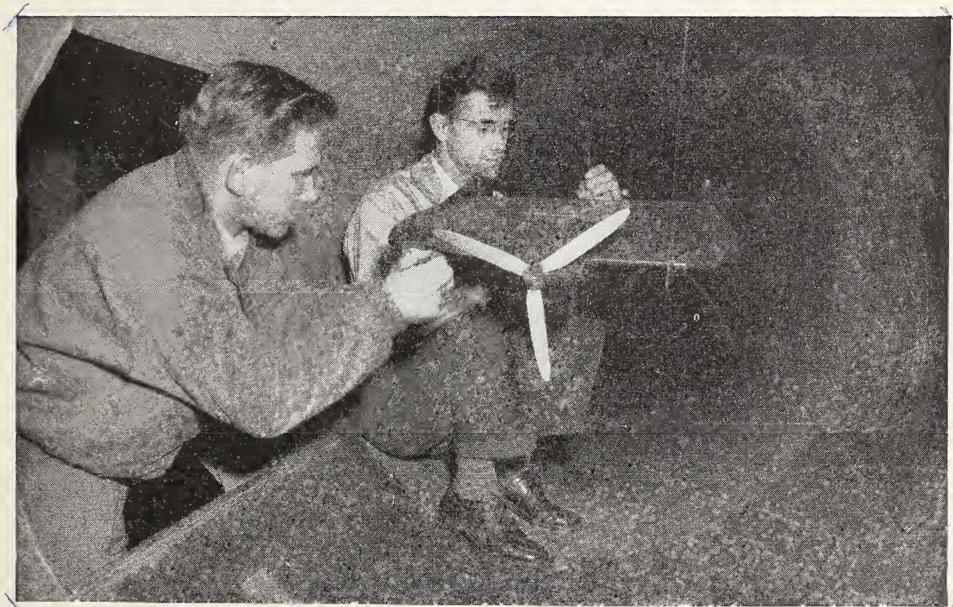
12. How does a pilot cause a plane to bank?

13. How does an altimeter work?

14. How does a tachometer help in flying a plane at night?

PROJECT

Making a Wind Tunnel. Mount an electric fan behind a grill about 1 foot square and 8 inches deep. A wooden box with its bottom removed and its inside filled with cardboard partitions like those in an egg box will be satisfactory. The partitions insure a straight flow of air with few whirls and eddies.



Courtesy Rhode Island State College

Fig. 33–17. Wind tunnel in an aeronautics laboratory. The students are arranging a plane to study the effects of streamlining.

Then mount the wing of a model airplane in front of the grill so that air flows past it smoothly. Tiny threads of silk glued on the wing surface will show where the air flows smoothly and where it is rough or turbulent. Another way of showing the air flow is to generate a white fog and blow it through the grill with the fan. Any smoke-producing material is satisfactory.

Change the angle of attack of the wing and watch the air flow over the top of the wing. What is the angle of attack when the flow becomes very turbulent? This is the angle at which the airplane wing *stalls* and fails to hold up the plane.

Try other shapes and study the flow of air past them. This will show you the advantages of streamlining. For instance, compare the flow of air past a cone-shaped piece of wood, with the point first toward and then away from the fan. Which way produces less drag?

Chapter 34

GAS TURBINES, JETS, AND ROCKETS

We have discussed the steam engine, which is a product of the 18th century, and the internal-combustion engine, which is a product of the 19th century. Now let us see what the 20th century has contributed to the advancement of transportation. Our century is a scientific age. In fifty years more advances have been made than in all preceding centuries taken together.

Scientists are now engaged in developing, among other things, more efficient engines; that is, engines that will do more work with less fuel. This means that they are looking for ways and means of preventing fuel waste. They are also interested in replacing expensive gasoline with cheaper and more abundant fuels. Is it possible to run an internal-combustion machine on water gas, coal gas, or even on powdered coal? This is an important question, since the supply of oil is limited and that of coal is far more abundant.

Another important problem is the simplification of the engine. Since the internal-combustion engine is a highly complex machine, its use entails frequent inspection of the parts and constant repairs, as well as the possibility of breakage at a critical time. The scientist strives to reduce risks as far as possible and to avoid unnecessary accidents. In passing from the steam engine to the internal-combustion engine, he employed two new principles: the combustion of fuel within a cylinder and electric sparking.

One result of scientific research has been greater and greater speed in travel. Distant places can now be reached easily and quickly; indeed San Francisco is less than five hours from New York; Europe is less than a day from the United States. The fact that distant places are easily accessible is of immense importance in our international social relationships. In his famous book *One World,* Wendell Willkie pointed a way to the removal of internal misunderstandings which are the seeds of war. Mutual understanding among nations can be advanced only if transportation is rapid and cheap.

Today we are interested in the centers of culture, both modern and ancient. But centers of culture are widely separated. Easy transportation therefore makes it possible for many of us to visit them and thus to appreciate and understand our cultural inheritance, and to further the exchange of cultures among the peoples of the earth.

Improved transportation has given rise to such an ambitious idea as the possibility of a trip to the moon or to the planet Mars. Some scientists believe that such a trip will become a reality during the 20th century. They are experimenting to devise the kind of "ship" that will be able to travel through space. But think of the difficulties involved in building an engine for such a journey! The engine needs oxygen for the combustion of a fuel. How can the oxygen be supplied as the ship travels through space where there is neither air nor oxygen? This is clearly a major problem;

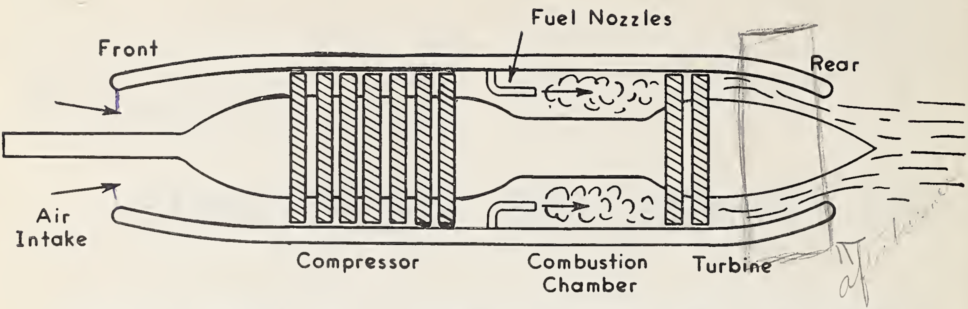


Fig. 34–1. Cross-section view of a gas turbine. The shaft may be used to drive a propeller, an electric generator, or a ship.

yet many scientists believe it can be solved.

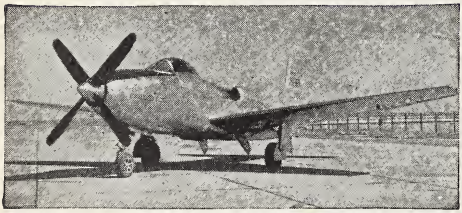
Let us now study a few of the engineering advances in transportation already made in the present century—the gas turbine, the jet, and the rocket.

The Gas Turbine. The gas turbine is really a combination of the internal-combustion engine and the steam turbine. Fuel gases—from gasoline, kerosene, fuel gas, or even powdered coal—burn inside the engine and spin a small turbine at high speed. The turbine can then be used to spin a propeller, turn an electric generator, or drive a locomotive.

The principal parts of this engine are a *compressor* to supply air, a *combustion chamber* where the air and fuel burn, and a *turbine* that produces the motion. We can follow the operation of these parts by studying Fig. 34–1.

When the engine is turning over, air enters the front end and is forced by the rapidly spinning compressor, which operates like a fan, into the combustion chamber. Here it combines with the fuel and burns. The heat of the flame increases both the temperature and the pressure of the gaseous products of combustion. These gases strike the blades of the turbine and turn them at high speed. The turbine is on the same shaft as the compressor, so that, once the engine has started, the turbine keeps the compressor and a fuel pump operating and the motor continues to run. The flame in the combustion chamber ignites the new fuel-air mixture as it enters, so that no ignition system is used after the first spark.

Many engines of this type have been built and tested, and the results show that ① the gas turbine is more efficient than either the steam turbine or the automobile engine. It is also ② much simpler to build, since all the cams, valves, and ignition of the ordinary engine are unnecessary. Moreover, kerosene is just as good as super-octane aviation gasoline for these engines and is much cheaper. With these advantages this new engine will certainly be adapted for general use and will be a serious competitor of the internal-combustion engine.



Courtesy U.S. Air Force

Fig. 34–2. The propeller of this experimental plane is driven by a gas turbine in the rear of the fuselage. (Note the air intake port just to the rear of the cockpit.) Such an arrangement is often called a "prop-jet" engine, since both propeller and jet help to move the plane.

The Jet. Another engine closely associated with the gas turbine is the *jet*. This engine, however, is designed only to produce motion; in other words, it will fly a plane but it will not turn a generator or a drill press. The jet plane is simple in design. It uses kerosene as a fuel, it has no propeller, and it will fly at elevations above 40,000 feet. The jet is faster than the ordinary plane. It has already been flown at a speed of more than 670 miles an hour.

The jet plane is designed to operate in accordance with a well-known law, first stated by Isaac Newton: *For every action there is an equal and opposite reaction.* This law means that when a locomotive, for example, moves *forward* it pushes *back* on the rails, which must therefore be fixed firmly to the ground; otherwise they would move. This push on the rails constitutes the *action*. The rails exert an equal *reaction* on the locomotive, and it is this thrust that causes the locomotive to move.

Courtesy *Royal Canadian Air Force*

Fig. 34–3. An R.C.A.F. F-86 Sabre Jet fighter capable of flying over 650 MPH. Its jet engine develops over 5,000 pounds thrust. This plane has a range of more than 1100 miles.

Likewise, if a boy in a canoe throws a rock over the stern of the canoe, he and the canoe move forward. His *action* of throwing the rocks is opposed by the *reaction* force of the rock against his hand, which pushes him forward. Thus both the rock and the thrower are made to move.

Suppose a person on roller skates throws a heavy weight, such as a medicine ball, away from him. If he is on a smooth floor, he will move backward almost as fast as the ball goes forward.

How can action and reaction be used to fly a plane? Let us find the answer to this question by watching the flight of an inflated balloon as air escapes from it.

Demonstration 34–1. The Flight of a Balloon.

Blow up a toy balloon and close it by holding the neck. Now release the balloon and observe that it takes off on an erratic flight of ten or twenty feet. Why?

The rounded shape of the balloon when blown up shows that the air inside is exerting an equal pressure in all directions, as shown in Fig. 34–4. That is, pressure *A* is balanced by pressure *B* and pressure *C* by pressure *D*; so nothing happens.

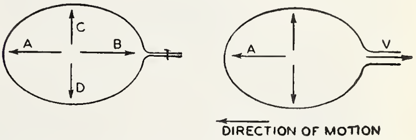


Fig. 34–4. The air in the inflated balloon exerts an equal pressure in all directions. When the air is allowed to escape, the released air upsets the balance of the pressure forces within the balloon.

When the gas escapes from the balloon, however, a different situation exists because there is no longer a force on the balloon at *B*. Instead, the balloon pushes the gas out at V, and this force is the *action*. The force A is now an unbalanced force; it is the *reaction* of the gas on the balloon. This unbalanced force makes the balloon move.

This motion would take place even in a vacuum, because it is the gas *inside* the balloon that causes the motion.

Direction of Motion. The jet engine works in a similar way, as shown in Fig. 34–5. Air enters the front of the engine and is forced by a rapidly rotating compressor into the combustion chamber, where it is mixed with fuel and burned. The high temperature increases the pressure of the air and gases, which then pass through a small turbine and out of the jet at the rear of the engine. The purpose of the turbine is to keep the compressor and fuel pump going in order to keep the engine working. The *thrust* of the engine is produced by the reaction to the expanding gases as they rush out of the jet with a velocity that may be as high as 1,400 miles per hour. In acting on the gases to force them out at this speed, the engine is subjected to a corresponding reaction that drives it forward with great force.

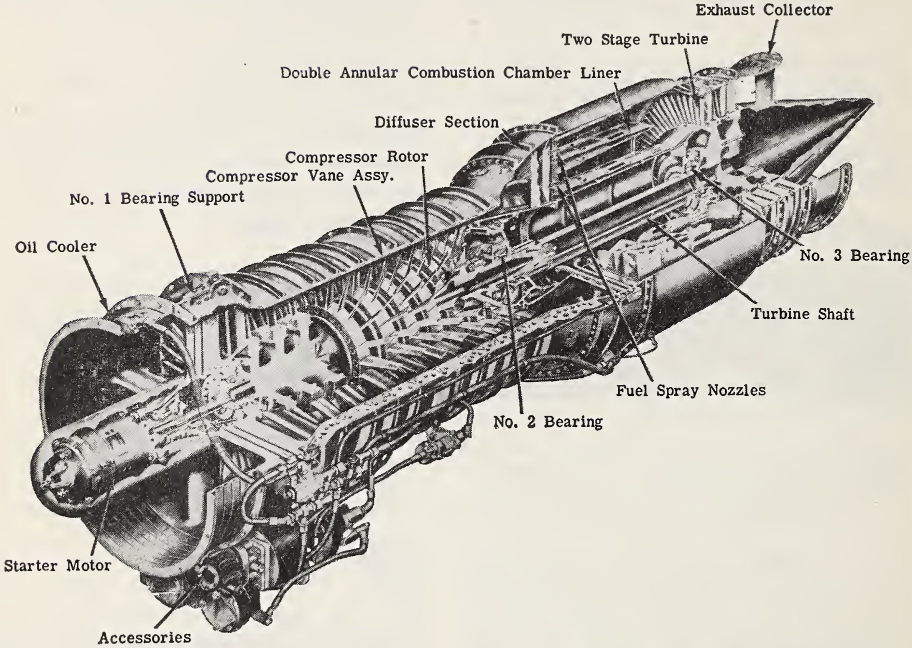


Fig. 34–5. Cut-away view of a turbo-jet engine showing its actual construction. Engines of this type, applying their thrust directly rather than through the medium of wheels or a propeller, develop a reaction thrust of over 5,000 pounds.

The F–84 Thunderjet, shown in Fig. 34–3, has a jet engine built into the fuselage near the pilot. This plane has flown at speeds greater than 650 miles per hour and to heights of over 40,000 feet. It is easier to fly than ordinary planes; it is quieter and has fewer meters and controls for the pilot to watch and operate.

One of the most spectacular uses of a jet engine during World War II was the flying bomb, or V-1 robot bomb. It was first used by the Germans to bomb London from launching sites in France, Belgium, and Holland. An official British statement described it as a miniature plane with a wingspan of 17 feet. The wings were about 2 feet wide and were placed about midway on a 21-foot fuselage. The body of the bomb contained over a ton of explosive, a fuel tank, and the control mechanism that guided its flight.

Rockets. Rockets have been used for centuries as weapons in war and in fireworks celebrations. The Chinese used flaming rocket fire arrows as incendiary devices as early as the 13th century. The British used improved rockets against France and against the United States in the early 19th century. But improvements in explosives and guns made even the best of these early rockets obsolete as weapons.

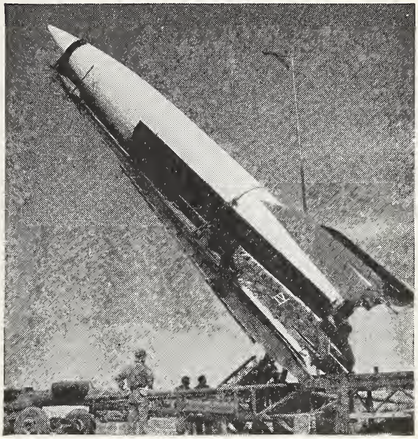
Rockets operate on the same basic principle as the jet; that is, gases are expelled backwards rapidly and the reaction drives the rocket forward. The main difference between the jet and the rocket is that the jet uses atmospheric air, whereas the rocket carries both its fuel and its oxygen supply. Since the rocket does not depend on the atmosphere for combustion, theoretically at least, a rocket could be used on a flight to the moon or to a planet such as Mars or Venus.

There are two broad classes of rockets: ①powder rockets and ②liquid-fuel rockets. We shall consider both types.

Powder Rockets. The fuel of the powder rocket is similar to ordinary gunpowder described on page 219, but the composition has been changed somewhat to make it burn more slowly and evenly. This fuel is packed firmly into the body of the rocket, but a tapering hole is left in the center of the powder. When the powder is ignited, it burns, producing gases which blow vigorously out of the jet at the rear of the rocket. The hole in the powder is the combustion chamber, which, of course, becomes larger as the powder burns. The larger the combustion chamber, the faster is the rate at which the gases are produced, so a rocket actually speeds up during its flight. The total burning time of a powder rocket is not more than a few seconds.

Early powder rockets were dangerous to use and erratic in flight. But rapid development of this type of rocket took place during World War II. The Germans were the first to use rocket guns on fighter planes. The range of the rocket was so much greater than that of ordinary machine guns that German fighters could stay out of range of a bomber's guns and yet hit the bomber with rockets. Americans were the first to use rockets from landing craft, and salvos of rockets helped to clear the beaches of Japanese before landings on the Pacific Islands.

Rockets have also been used to assist heavily loaded aircraft to take off after relatively short runs. This permitted them to be launched from the deck of a carrier. Rockets have been similarly used to assist take-offs in peacetime.



Courtesy U.S. Army Signal Corps

Fig. 34–6. A V–2 rocket is lifted gently into firing position for tests at the White Sands Proving Ground. Scientific instruments were carried aloft to record information about conditions in the atmosphere 70 miles above the earth.

Liquid-Fuel Rockets. Liquid-fuel rockets carry a fuel, such as alcohol, and liquid oxygen for producing combustion. These liquids are injected under pressure into the combustion chamber, where they react and produce hot gases which are blown violently out the jet. Alcohol contains carbon, hydrogen, and oxygen, and it is a powerful but ①expensive fuel.

Such rockets are still largely in the experimental or developmental stage. One of the difficulties, for instance, is the ②handling of liquid oxygen, which must be maintained at a temperature of nearly −190° C. At this low temperature, moisture condenses and freezes on the tank and on all pipes carrying the liquid oxygen. In consequence, pumps used for injecting it into the combustion chamber may also freeze; and the whole equipment is thus dangerously explosive.

Courtesy Lockheed Aircraft Corp.

Fig. 34–7. Lockheed F–80C Shooting Stars.

In spite of these difficulties the Germans developed the V-2 rocket, using liquid oxygen and alcohol for fuels. Such rockets, shown in Fig. 34–6, were used as a terror weapon against England toward the end of World War II. Some of them exploded before they left the ground, but many made "successful" flights. They climbed almost 70 miles into the stratosphere, then leveled off and flew at a speed of over 3,000 miles an hour toward their target. Finally, they nosed down and approached the target at a speed greater than that of sound, so that their approach could not be heard. It was the silent approach that made this rocket one of the most terrifying weapons of the war.

Today rockets are our only means of exploring the upper layers of the atmosphere. Government scientists have sent many captured German V-2 rockets, carrying scientific instruments, into the stratosphere at altitudes of more than 100 miles. The instruments measure such things as temperature, the nature of the upper atmosphere, and the sun's spectrum.

The use of liquid-fuel rockets as engines for global and interplanetary flight holds fascinating possibilities. However, atomic energy may supplant liquid fuel as the source of power in future rockets. The major disadvantage of liquid-fuel rockets as commercial engines lies in the tremendous amount of fuel that must be carried even for short flights. For instance, 11,000 pounds of liquid oxygen and 7,500 pounds of alcohol are used to raise a rocket about 70 miles above the earth. This difficulty would presumably not exist with atomic power, but much more research and development must be carried out before either form of power is ready for everyday use.

THINGS TO REMEMBER

A *gas turbine* burns in its combustion chamber a mixture of air and fuel. The resulting gases turn a turbine that can be used to drive such devices as propellers or electric generators.

A *jet engine* burns air and fuel and then ejects the gases at the rear of the engine. It is designed only for producing motion; it cannot operate in a vacuum.

A *rocket* carries its own oxygen supply as well as its fuel; therefore it can work in a vacuum. Otherwise it acts in the same way as a jet.

Newton's law states that for every *action* there is an equal and opposite *reaction.*

In the operation of the jet and the rocket, *ejection of the gases backward drives the engine forward.*

QUESTIONS

A

1. Determine which of the following statements are true and which are false. Then correctly reword the false ones.
   (*a*) A jet is an internal-combustion engine.
   (*b*) A jet uses kerosene as a fuel.
   (*c*) Sir Isaac Newton first explained how to construct airplanes.
   (*d*) Liquid-fuel rockets have been used for centuries.
   (*e*) Rockets carry their own oxygen supply.

2. Name the principal parts of a gas turbine.

3. What fuels can a gas turbine utilize?

4. Why might we call a gas turbine an "internal-combustion" turbine?

5. Does a plane powered with a gas turbine have a propeller? Explain.

6. Can a jet engine be used to run a sawmill? Explain.

7. State Newton's law of action and reaction.

8. Why will rockets rather than jets be used for interplanetary travel?

B

9. Why are you able to run *forward?* Use Newton's law in your explanation.

10. Describe the advances in transportation made in the 18th, 19th, and 20th centuries.

11. How does a jet engine differ from a gas turbine?

12. How does a rocket differ from a jet?

13. What major factor will limit the maximum altitude to which a jet plane can be flown?

14. Explain why an inflated rubber balloon moves when released with its mouth open.

15. Describe the combustion of the fuel during the flight of a powder rocket.

16. (*a*) Name two difficulties encountered in the development of liquid-fuel rockets.
   (*b*) Would atomic power overcome these difficulties? Explain.

17. Write an imaginary, though reasonable, essay describing the possible means of transportation at the end of the present century.

PROJECTS

1. *To Build a Reaction Jet.* Build a small wooden boat about 10 inches long and 3 inches wide. Mount a can of sterno under a funnel whose bent stem points toward the rear of the boat. Light the burner and watch the boat go. What makes it move? Is it like a gas turbine, a jet, or a rocket?

2. *Testing a Model Jet Plane.* Some model airplanes are built with jets. Write to a model-aircraft supply house for information on the types available.

   If you build a plane using such a jet, test its power or thrust on the ground by hooking a small spring balance to the tail skid with a light wire. How does the thrust compare with that of a model plane powered with a gasoline engine?

REVIEW QUESTIONS ON UNIT 6

A

1. What is meant by the components of a force?

2. On what does the mechanical advantage of scissors depend?

3. A boy weighing 150 pounds climbs a vertical ladder to a height of 20 feet. How much work does he do?

4. Name three important differences between gasoline engines and Diesel engines.

5. What kind of cooling system is commonly used in a gasoline engine?

6. Should a Diesel engine have a cooling system? Explain.

7. Compare the operation of a carburetor with that of an injector.

8. Describe the action of the cylinders of a four-cycle engine during each of its four strokes.

9. How does the lifting effect on a balloon differ from that on an airplane?

10. The lift on an airplane wing is a component of what force?

11. Name two factors that limit the height to which airplanes powered with internal-combustion engines can go.

12. How does a jet engine work?

13. Complete each of the following statements by supplying the correct word or phrase.

(*a*) An engine is a device for changing —?— chemical energy into —?— mechanical.

(*b*) In a four-cycle gasoline engine the —?— piston of a cylinder is forced down by the hot gases every —?— power stroke.

(*c*) In a jet engine the rapid ejection of hot —?— gas toward the rear drives the engine —?— forward.

(*d*) The main moving parts of a gas-turbine engine are the —?— blades of the —?— turbine.

14. Determine which of the following statements are true and which are false. Then correctly reword the false ones.

(*a*) The fuel in a Diesel engine is ignited by means of a spark plug.

(*b*) A steam turbine needs no automatic valves for its operation. T

(*c*) Rockets may some day be able to travel to the moon because they carry all their fuel with them. T

(*d*) A jet-propulsion engine is more complex than a Diesel.

(*e*) Diesel engines commonly use gasoline as a fuel.

B

15. Would a pulley system with a mechanical advantage of 40 be reasonable? Explain.

16. When 100 foot-pounds of work are put into a pulley system, 60 foot-pounds of work are obtained from it. What is the efficiency of the system?

17. A man wishes to lift one end of an automobile 4 inches. Would it be easier to use a pulley system or a long plank? Explain.

18. A painter usually hoists himself up the side of a building with the help of a single fixed pulley on the roof. One day he injured his arm and had a friend on the ground hoist him up, but the rope broke. Can you give a reason for this?

19. Match each word in the left-hand column with the word it is most closely related to in the right-hand column.

Carburetor
Condenser
Fuel injector
Powder fuel
Steam nozzles

Diesel engine
Steam engine
Steam turbine
Rocket engine
Gasoline engine

20. Name four different types of heat engines. Tell how each obtains its fuel, its air supply, and its ignition.

21. Which of the answers to each of the following statements is correct?

(*a*) The fuel in a Diesel engine is ignited by: (1) an electric spark; (2) a small flame; (3) the heat produced by compressing a gas; (4) a chemical reaction which produces heat.

(*b*) One of the principal advantages of a rocket engine is that it: (1) carries its own supply of oxygen; (2) carries its own supply of fuel; (3) works well at low speeds.

(*c*) A gasoline engine will start: (1) by itself; (2) when the ignition is turned on; (3) only when it is cranked.

(*d*) One of the principal advantages of a steam engine that burns coal as a fuel is that: (1) coal is cheap; (2) coal contains more heat per pound than other fuels; (3) the heat wasted keeps the engineer warm.

(*e*) One of the chief advantages of a condenser on a steam turbine is that: (1) it keeps the pressure high at the exhaust; (2) it can be used to make the turbine go backward; (3) it prevents the loss of pure water; (4) it helps the engine use more coal per unit weight of steam produced.

22. How does steering a car around a corner differ from guiding an airplane around a corner?

23. How does Newton's third law apply to an airplane in steady, level flight?

24. Does Newton's third law still apply to an airplane when it is climbing?

SUGGESTIONS FOR FURTHER READING

A

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Unit 7

ELECTRICITY

35. WHAT IS ELECTRICITY?
36. ELECTRIC CURRENTS
37. MAGNETISM
38. ELECTRIC POWER
39. HEAT AND LIGHT FROM ELECTRICITY

WHAT IS ELECTRICITY?

Can you imagine what our living would be like if we had no electricity? Within the past century man has discovered hundreds of ways to turn electricity to his use. In our homes, we see the refrigerator, the vacuum cleaner, lamps, the heater, the electric iron, the radio, the telephone, and the doorbell, all operated by electricity. In industry, electricity plays an even more important role. It operates lathes and all other kinds of machines in factories; it is used for welding steel girders for skyscrapers. It is used to separate some metals from their ores. Aluminum, for instance, which now replaces steel for many purposes, is obtained from the mineral bauxite by electricity. Electricity is used for countless other purposes, some of which we shall discuss in later chapters.

Where does electricity come from? You know that it travels along transmission lines to the home, office, and factory. But what sends electricity out over the transmission line? If we follow the transmission line back to its source, we shall probably arrive at a large building with tall smokestacks called a *power station.* Here we find huge electric generators, some of which are described in a later chapter. The energy of coal operates a steam turbine, and this, in turn, operates the machine that generates our electricity. Not all electricity, however, is generated from coal; a great deal of it is obtained from water power. Nevertheless, more than 60 percent of the electricity in the United States is derived from coal through the medium of the steam turbine. Let us now examine some of the ways of producing electricity.

Electricity from Friction. One of the easiest ways to produce electricity is to rub together two different surfaces such as glass and silk, or fur and hard rubber. In Chapter 3, you will recall, we showed that an electrified rod attracts small pieces of paper. Some rods can be charged positively and some negatively, as the following experiment shows.

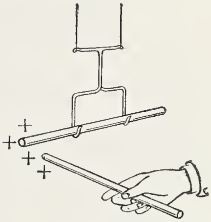


Fig. 35–1. Like charges repel each other.

Demonstration 35–1. Positive and Negative Charges by Friction.

Rub one end of a glass rod vigorously with a piece of silk and then suspend the rod from a support, as shown in Fig. 35–1. Now rub another glass rod in the same way and hold it close to the rubbed end of the suspended rod. You will observe that the suspended rod is pushed away, or *repelled.* Now rub a hard-rubber or Bakelite rod with fur and bring it close to the suspended glass rod. You will find that this time the glass rod is *attracted* by the hard rubber rod. Why is the suspended rod repelled in one case and attracted in another? *Note:* When there is too much moisture in the air the electric charges leak off almost as fast as they are produced. Therefore this experiment usually works better in winter than in summer.

Electrons and Protons. To understand why the rod was attracted in one case and repelled in the other, recall what you learned about atoms in Chapter 3. Matter is made up of *atoms*. Atoms contain *electrons* and *protons*. Each electron has a small quantity of electric charge called a *negative* charge. It also has mass, but the mass and the charge cannot be separated. A proton, though exceedingly small, is about 1,800 times as heavy as an electron. Each proton also has a charge. Because this charge is opposite in kind to that of the electron, it is called a proton *positive* charge. Normally every atom has as many protons as electrons and is therefore *neutral* electrically.

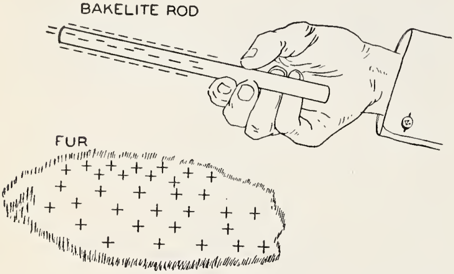


Fig. 35–2. When the Bakelite rod is rubbed with fur, electrons are removed from the fur by the rod.

When the glass rod was rubbed with the silk, electrons were pulled off the atoms on the surface of the glass. Thus the glass was charged *positively* because it was left with more protons than electrons. The fact that a second positively charged glass rod repelled the first rod (see Fig. 35–1) shows that *positive charges repel each other*. When the Bakelite rod was rubbed with the fur, electrons were removed from the fur by the rod, leaving the fur positively charged and giving the Bakelite rod a negative charge. This is shown in Fig. 35–2. Since the negatively charged rod *attracted* the positively charged glass rod, we conclude that *unlike charges attract each other*.

We must remember that, whether a rod is charged negatively or positively, the charge is due to the transfer of electrons, the light electrons being much more easily displaced than the heavy protons. A gain of electrons results in a negative charge; a loss of electrons results in a positive charge.

Let us now see what happens when a negatively charged rod supported by a thread is approached with another negatively charged rod. We find that the two rods repel each other. That is, *negative charges repel each other*. Therefore the results of our experiments show that *unlike charges attract each other and like charges repel each other*.

Examples of Electricity Produced by Friction. You may have noticed that large gasoline trucks often have a small chain hanging from the frame of the truck and dragging on the ground. As a result of the friction caused by motion electric charges are built up on the truck. If these charges were allowed to accumulate, they would cause a spark that might ignite the gasoline vapor and start a fire. The chain prevents this by carrying the charges to the ground.

Another precaution against accumulated charges is found on bridges and tunnels that carry heavy automobile traffic. Before a vehicle reaches the tollhouse, it passes over a short, flexible wire protruding from the ground. The purpose of this wire is to discharge the vehicle so that neither the toll collector nor the car driver will receive a shock as the money is being passed.

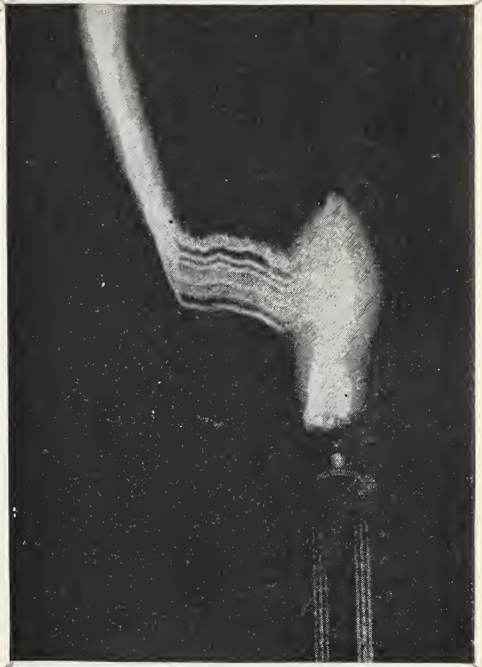
It is the insulating properties of the rubber tires on automobiles that prevent the accumulated charge from escaping to the ground. In a similar way, electric charges are built up on the moving belts that carry power to machinery in factories. In order to prevent such an accumulation of charges, the machines to which the belts are connected are grounded by a heavy wire running from the machine into the earth.

Even the everyday process of combing the hair produces electricity by friction. On a dry day when you run a comb through your hair, you can hear the crackle of electric sparks, and in a dark room these sparks may even be seen. During the combing, electrons are removed from the hair and collect on the comb, leaving each hair with a positive charge. The combing may even cause your hair to stand on end. Why does this happen?

Insulators and Conductors. In general, when two dissimilar materials are rubbed together, one material becomes positively charged and the other negatively. But when a metallic substance is rubbed with fur, the electrons will run from the metal to the ground unless the metal is supported by a substance like Bakelite or glass to prevent them from doing so. This is true because metals are *conductors*; that is, they are substances in which electrons can move freely from atom to atom. Substances like glass, sulfur, rubber, Bakelite, or plastic, in which electrons cannot move about freely, are called *insulators.* A glass handle attached to a metal object that is rubbed will therefore prevent the electrons from running to the ground, and the metal object will remain charged. It is interesting to note that *good conductors of heat are also good conductors of electricity*.

Electricity in Nature. Electricity is also produced in nature. A flash of lightning, which is nothing more than a giant electric spark, is a spectacular example. In 1752 Benjamin Franklin performed a striking experiment. During a thunderstorm he flew a kite provided with an iron point. For string he used a silk cord. To the lower end of the cord he attached a metal key. Franklin found that whenever he touched the key he obtained a spark. In this way he proved that electricity could be drawn from a thundercloud.

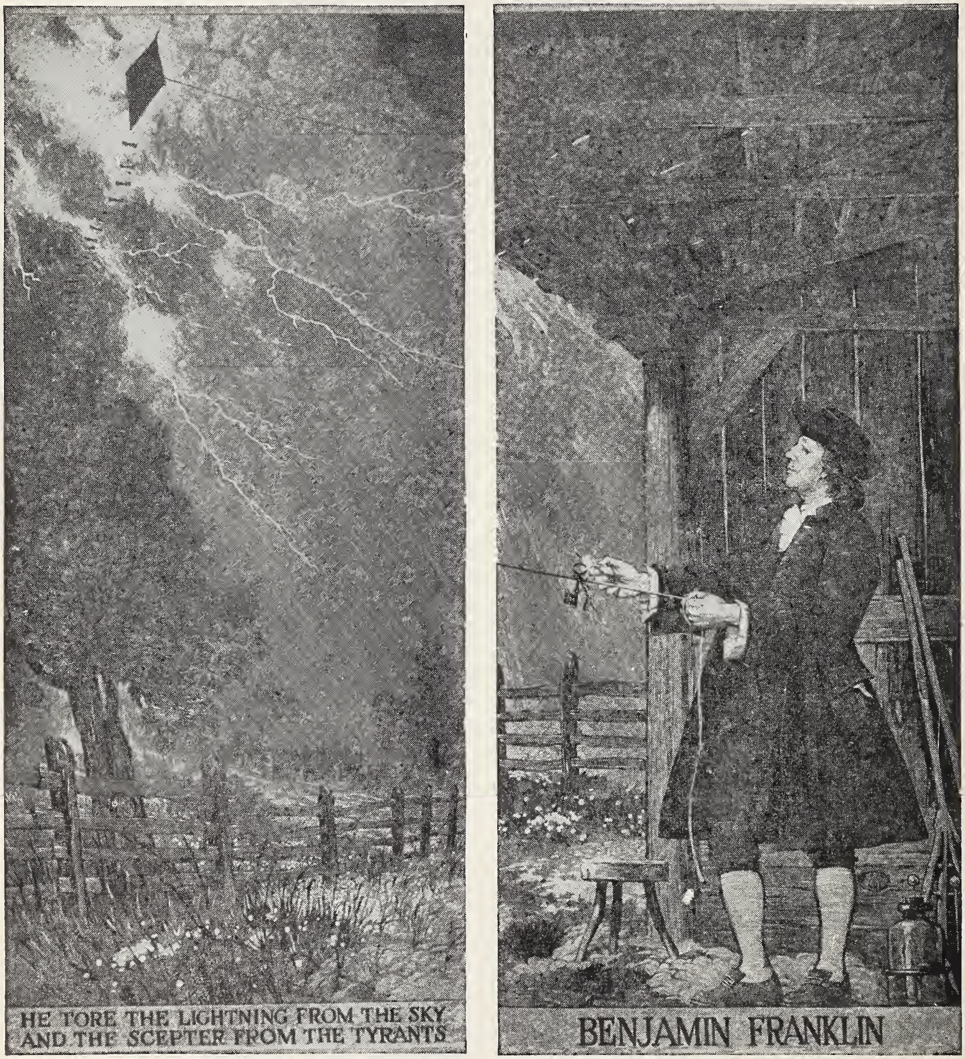
This experiment led to the use of lightning rods to protect buildings against lightning. A lightning rod consists of a copper rod, with a sharp point, attached to a flat band of copper that runs down the side of the building as shown in Fig. 35–5. Connected to the copper strap is a copper plate that is buried in the ground.



Courtesy General Electric Co.

Fig. 35–3. Lightning strikes the top of the Empire State Building in New York City. A large lightning rod at the top of the building conducts the charge down to the steel frame of the building through which it runs off harmlessly into the ground. This building projects so far above surrounding buildings that it is often struck during thunderstorms.

The Cause of Lightning. The tremendous amounts of electric charge which cause lightning flashes in thunderstorms are probably produced by friction. Usually the top of a thundercloud is positively charged and the bottom is negatively charged. The exact manner in which the bottom of a thundercloud becomes heavily charged with electrons is not well understood. However, it is probably the result of the friction produced by the violent


HE TORE THE LIGHTNING FROM THE SKY
AND THE SCEPTER FROM THE TYRANTS
BENJAMIN FRANKLIN

Courtesy The Franklin Institute

Fig. 35–4. Two murals depicting Benjamin Franklin's famous kite experiment in which he showed that lightning is a form of electricity.

updrafts and downdrafts in a cumulonimbus cloud. Large drops of water are broken up into smaller ones by these air currents, and at the same time electrons are lost by some droplets and gained by others.

When a positively charged cloud drifts close enough to a negatively charged cloud, the air suddenly becomes a conductor and a flash of lightning takes place between the clouds. The thunder is caused by the sudden expansion of the air, heated intensely by the large flow of electricity. This sudden expansion sends out a sound wave that we hear as a clap of thunder.

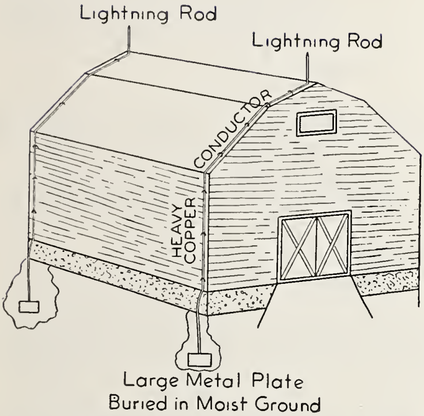


Fig. 35–5. A barn protected by lightning rods.

Sometimes a negatively charged cloud comes so close to the ground that a lightning flash takes place between the cloud and the earth. The negatively charged cloud induces a positive charge on objects projecting above the earth by repelling electrons from these objects into the earth. If the induced positive charge becomes large enough, a sudden flash of lightning from cloud to ground discharges the cloud.

If a heavily charged thundercloud passes close over a building protected by a lightning rod, the charge leaks off slowly to the ground through the sharp point, and the chance of a sudden direct flash of lightning to the building is greatly reduced.

This function of the lightning rod explains why it is dangerous to take shelter under a lone tree during a thunderstorm. The tree, which projects well above its surroundings, is likely to be struck by lightning. Unlike a copper lightning rod, the tree is a poor conductor. The electricity might therefore jump from the tree to a person standing close by and kill him. It is much safer to seek shelter in a building than under a tall tree.

Lightening

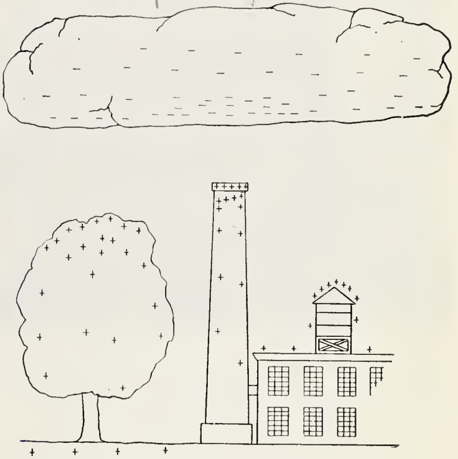
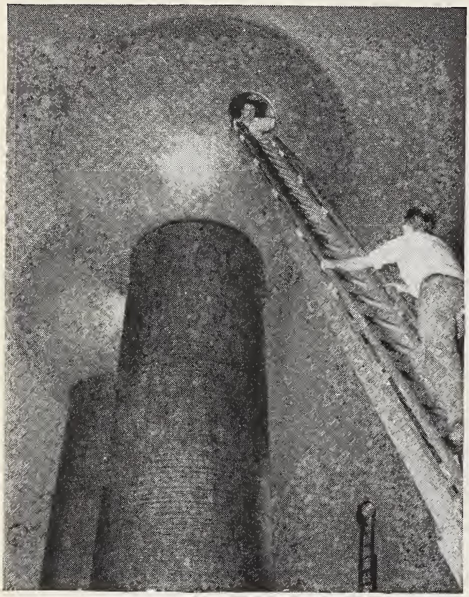


Fig. 35–6. A low-hanging negatively charged cloud induces a positive charge in objects on the ground.

The Van de Graaff Generator. Man cannot make use of natural lightning because it is uncontrollable and too dangerous. However, various types of machines capable of producing artificial lightning have been built. These machines can be safely used in finding out more about the properties of lightning. One such machine, the Van de Graaff generator, consists of two large metal spheres supported on hollow insulating columns. As shown in Fig. 35–7B, each column contains a belt running over pulleys in the base and in the hollow spheres. These belts are driven by electric motors. In one column, electrons, supplied at the base, are carried by a belt to one of the spheres, which is therefore charged negatively. In the other column, electrons are carried away from the sphere, leaving it charged positively. If the spheres become charged to a sufficiently high voltage, a discharge in the form of a flash of artificial lightning takes place between them. Van de Graaff generators are often used to provide extremely high voltages for large X-ray machines and for the apparatus used in the study of the nucleus of the atom.



Courtesy Massachusetts Institute of Technology

Fig. 35–7A. A huge Van de Graaff generator built for bombardment of atomic nuclei at a potential of more than two million volts.

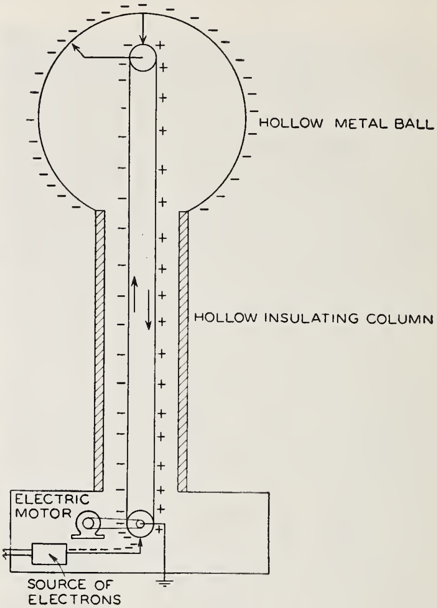


Fig. 35–7B. Diagram of one element of a Van de Graaff generator showing how it is charged negatively.

THINGS TO REMEMBER

All atoms contain *protons* and *electrons*.

An *electron* is the smallest particle of matter and has a *negative* charge.

A *proton*, though very small, is about 1,800 times as heavy as an electron and has a *positive* charge.

Most atoms are *electrically neutral;* they contain equal numbers of protons and electrons.

Like charges *repel* each other; *unlike* charges *attract*.

A *conductor* is a substance in which electrons can move about easily from one atom to another.

Metals are good *conductors* of electricity.

An *insulator* is a substance in which the electrons cannot move easily from one atom to another.

Glass, sulfur, rubber, Bakelite, and plastics are good *insulators*.

QUESTIONS

A

1. What did Benjamin Franklin prove with his famous kite experiment?
2. How does a lightning rod work?
3. How would you obtain: (*a*) a positive charge; (*b*) a negative charge?
4. (*a*) What is an electron?
   (*b*) What is a proton?
5. State the law of charges.
6. Name four substances that are: (*a*) good conductors of electricity; (*b*) good insulators.
7. Why do gasoline trucks often have a piece of chain dragging on the ground?
8. What is the cause of lightning?
9. What is the cause of thunder?

B

10. Determine which of the following statements are true and which are false. Then correctly reword the false ones.
    F (*a*) ~~Protons~~ are negatively charged.
    T (*b*) An electron weighs only $\frac{1}{1800}$ as much as a proton.
    F (*c*) Like charges attract and unlike charges repel.
    F (*d*) Electrons move easily throughout an insulator.
    T (*e*) A positive charge appears on a glass rod when it is rubbed with silk.
    (*f*) When a glass rod is rubbed with silk, protons are moved from the silk to the rod.
11. Describe exactly what happens when a glass rod is rubbed with silk, and when a hard rubber rod is rubbed with fur.
12. Describe an experiment that would prove that like charges repel and unlike charges attract.
13. Describe exactly what happens before and during a lightning flash between a cloud and the ground.
14. How do clouds become charged?
15. Describe the construction and operation of a Van de Graaff generator.

PROJECTS

1. *Constructing an Electric Hoop.* Make a paper hoop from a strip of paper about 11 inches long and ¾ inch wide. Join the ends with a little paste to form the hoop. This hoop will roll along and follow a charged hard-rubber rod all over a table top. The hoop is attracted to the rod because the negative charges of the rod *induce* positive charges in the hoop.
2. *Photographing Lightning.* Excellent photographs of lightning flashes may be obtained during a thunderstorm at night by placing a camera in the open window of a dark room so that it faces an unobstructed portion of the sky and horizon. There should be no nearby sources of light, such as street lights outdoors. Set the camera at time exposure and leave it exposed until any desired number of lightning flashes have been observed.

   When the film is developed, there should be several interesting flashes visible. Many important facts about lightning have been discovered by pictures taken in a similar manner.

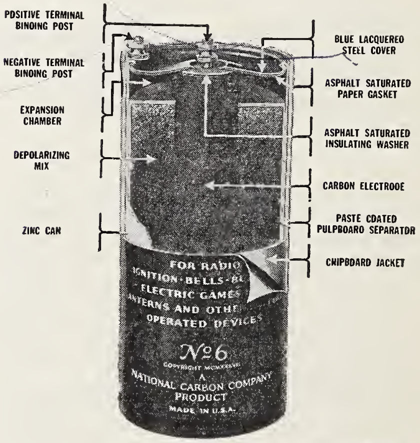
Chapter 36

ELECTRIC CURRENTS

Although electricity is indispensable in modern civilization, that which results from friction is of little practical value. And all attempts to store and use the electricity produced in lightning flashes have failed. Since the days of Benjamin Franklin scientists have tried to obtain electricity in a convenient and practical form. Two devices have been developed that are now used almost universally as sources of electricity. The *generator*, or *dynamo*, which utilizes a magnetic field is discussed in Chapter 38. The *electric cell*, or *battery*, generates electricity by chemical action. It is used in flashlights, automobiles, airplanes, and portable radios.

The first electric cell was made by Galvani, an Italian scientist, in the 18th century. Since that time electric cells have been greatly improved. We now have two convenient and efficient electric cells. One is the *dry cell;* the other, which contains a liquid, is commonly called the *storage cell.*

Dry Cells. Dry cells are made in various sizes and shapes, but all are constructed in a similar manner and contain the same materials. A dry cell is shown in Fig. 36–1. It contains a central rod of carbon surrounded by a damp paste of ammonium chloride mixed with clay, graphite, and manganese dioxide. This mixture is held in a cylindrical zinc container. The top of the cell is sealed to prevent the damp mixture from drying out. There are two screw terminals, or binding posts, to which wires may be connected. One terminal is fastened to the carbon rod; it is called the *positive* terminal because the current flows *from* it. The other terminal is attached to the zinc container; it is called the *negative* terminal because the current flows *into* it.



Courtesy National Carbon Co.

Fig. 36–1. A cross-section view of a dry cell.

This is the conventional way of stating the direction of current. Before electrons were discovered, scientists believed that an electric current was a flow of positive charges from the positive to the negative terminal. Though we now know that current is a flow of electrons from the negative to the positive terminal, we still say that *current* flows from the positive to the negative terminal.

If one end of a piece of copper wire is connected to the positive terminal and the other end to the negative terminal of the cell, a chemical action takes place in the cell. The reaction develops an electric force called an *electromotive force*, or *voltage*, that causes a current to flow. Unlike the sudden and violent surge of the charge in a stroke of lightning, this current is a steady flow of electrons that will last until the materials of the cell are used up. The rate at which an electric current flows is measured in *amperes*, named after Ampère, a famous French physicist. The electromotive force that causes the current is measured in *volts*, named after Volta, the Italian scientist who improved Galvani's simple electric cell.

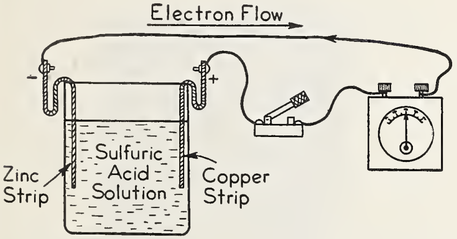


Fig. 36–2. Producing an electric current with a simple galvanic cell.

The common large dry cell develops a voltage of about 1.5 volts and, when new, will give a maximum current of from 30 to 40 amperes. Current and voltage are measured by electric meters, which are discussed later in the chapter.

Demonstration 36–1. To Produce an Electric Current by a Chemical Reaction.

Arrange a large glass jar, a piece of copper, and a piece of zinc as shown in Fig. 36–2. Almost fill the jar with dilute sulfuric acid and connect wires from the two metal plates to a galvanometer and switch as shown in the diagram. When you close the switch, a movement of the galvanometer needle indicates an electric current.

In the chemical reaction that takes place between the zinc and the acid, electrons from the negative zinc terminal are forced through the galvanometer to the positive copper terminal.

Circuits. As we have already seen, it is necessary to connect the two terminals of a cell with a piece of conducting wire in order to get a current from the cell. This is true of all electric apparatus that is used with cells and generators. There must be a good conducting path from one terminal of a cell or generator to one terminal of the electric apparatus, then through the apparatus to its other terminal, and back to the other terminal on the cell or generator. This flow of electrons from cell to apparatus and back to the cell is called a *circuit*.

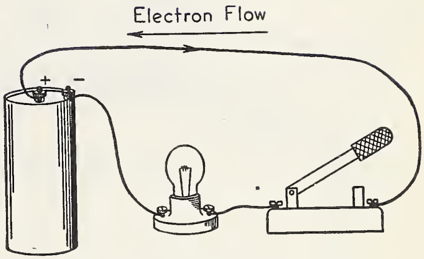


Fig. 36–3. A simple electric circuit.

Demonstration 36–2. A Simple Electric Circuit.

Connect a dry cell, a flashlight bulb, a small socket, and a knife switch with insulated copper wire as shown in the circuit in Fig. 36–3. Be sure that all the connections are tight and that the bulb is screwed securely in its socket. Now close the switch and observe that the bulb lights up.

Closing the switch completes the circuit and allows the voltage of the dry cell to force a current around the circuit and through the bulb, causing it to light. If the circuit is broken, the light goes out. This can be shown by disconnecting the wire at any point in the circuit. The switch is merely a convenient device for making and breaking the circuit.

To simplify the drawing of electric circuits, certain standard symbols are used for batteries, switches, resistors, etc., in a *schematic diagram*. These symbols are shown in Fig. 36–4, along with a schematic diagram of the circuit used in Demonstration 36–2.

Cells in Series. Sometimes a voltage greater than the 1.5 volts provided by a single dry cell is needed in order to force more current through a circuit. Voltage can be increased if two or more cells are connected so that a wire runs from the positive terminal of one cell to the negative terminal of the next and so on, as shown in Fig. 36–5. These cells are connected *in series*. The voltage produced by cells connected in series is the sum of the voltages of the individual cells. Let us see the effect of connecting cells in this manner.

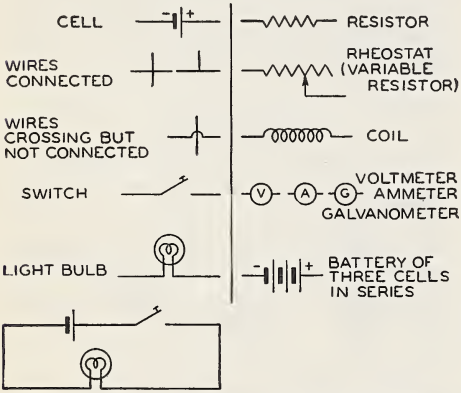

CELL
−
+
WIRES CONNECTED
WIRES CROSSING BUT NOT CONNECTED
SWITCH
LIGHT BULB
RESISTOR
RHEOSTAT (VARIABLE RESISTOR)
COIL
V
A
G
VOLTMETER
AMMETER
GALVANOMETER
BATTERY OF THREE CELLS IN SERIES

Fig. 36–4. Standard electric symbols and a schematic diagram of the simple electric circuit illustrated in Fig. 36–3.

Demonstration 36–3. Cells Connected in Series.

Set up the circuit used in the preceding demonstration and take particular note of the brightness of the light. Now connect two cells in series and notice that the light is brighter. This is due to the fact that the increased voltage forces a larger current through the light bulb. With three cells in series the light will be brighter still. (If more than three cells are used, the current may burn out the bulb.)

A large number of small cells connected in series and enclosed in one case as a single unit form a *battery*. Such batteries supply a high voltage. Those used in portable radios, for instance, give voltages of 67 volts or higher.

Storage Batteries. Dry-cell batteries are cheap and portable, but unfortunately they are not permanent. Once they have run down, they must be thrown away and replaced by new ones. Another type of battery, called a *storage battery*, though heavy and bulky, has the advantage of a much longer life. A storage battery can be recharged when it has run down, and with good care it will last several years in cases where dry cells would have to be replaced in a few weeks or even days. Storage batteries are used in automobiles, on railroad cars, airplanes, and submarines, to name only a few of their many uses.

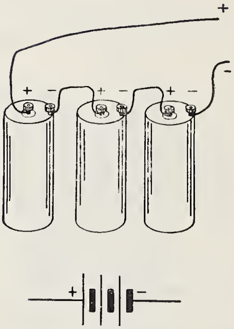
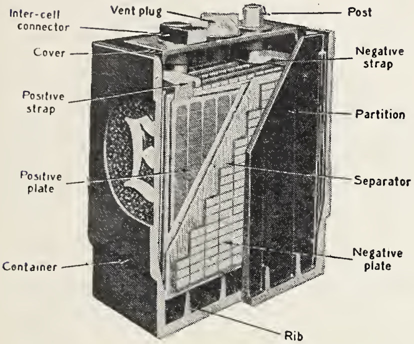


Fig. 36–5. Cells connected in series.

A simple storage cell (Fig. 36–6) has two electrodes (lead, negative; and lead dioxide, positive) immersed in dilute sulfuric acid. In an automobile battery the electrodes and the acid are enclosed in a hard rubber case. The electrodes are made in the form of interlocking plates and are kept apart by insulating separators. The plates and separators occupy the whole case except for the space between them, which is filled with sulfuric acid. In most automobile batteries three cells are connected in series and mounted in a single case. Each cell provides 2 volts, and the battery therefore gives 6 volts.

As the battery is used, or discharged, the resulting chemical reaction deposits lead sulfate on both electrodes, thus decreasing the concentration of sulfuric acid. When too much lead sulfate has been deposited on the plates, the battery becomes weak and must be recharged.

A storage battery is charged by passing current through it in the direction opposite to that in which it normally flows through the cell. In an automobile this is done automatically by the car generator whenever the motor is running above a certain speed. The battery therefore needs no attention except that distilled water must be added occasionally to replace the water lost by evaporation.



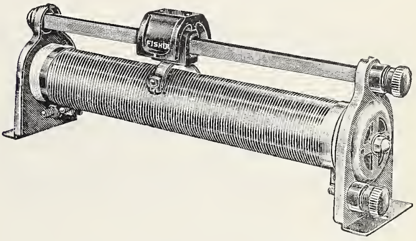
Courtesy Electric Storage Battery Co.

Fig. 36–6. One cell of an automobile storage battery cut away to show its construction.

Resistance. We have already discussed the difference between conductors and insulators. Let us now see how conductors and insulators function in electric circuits. A good insulator, such as Bakelite, cannot be used to connect the different parts of an electric circuit, since it would offer so much resistance to the flow of electrons that little or no current would flow. Even copper wire, which is a good conductor, however, impedes the flow of current slightly.

The resistance of any conductor depends upon its length; *the longer the wire, the greater is its resistance*. Thus a wire 10 miles long, such as might be used on an electric power line, has a resistance 10 × 5,280 or 52,800 times as great as the resistance of one foot of the same wire. Long wires that carry a heavy current are usually of large diameter since *the resistance of a conductor decreases as the area of its cross section increases*. Thus a wire with a cross section of $\frac{1}{5}$ square inch has a resistance that is $\frac{1}{100}$ that of the same length wire whose cross-section area is $\frac{1}{500}$ square inch.

If the current flowing through a circuit is to be reduced, a long length of fine resistance wire (usually a metal that is a relatively poor conductor) can be connected in series in the circuit. Such a device is called a *resistor*. If the wire can be varied in length and hence in resistance, it is called a *variable resistor*, or *rheostat*.



Fisher Scientific Co.

Fig. 36–7. A rheostat or variable resistor.

The unit of resistance is the *ohm*, named after the German scientist Ohm. The resistance of an ordinary 60-watt electric bulb is about 200 ohms.

Demonstration 36–4. To Vary the Current in a Circuit.

Connect the circuit used in Demonstration 36–3, using two cells, but place a rheostat in series in the circuit between the battery and the light-bulb socket. Close the switch and observe the effect of varying the resistance of the rheostat.

If the sliding contact on the rheostat is moved to a position such that the current must flow through the whole of the rheostat coil, the bulb becomes dimmer. This means that the current is decreased. This is what we might expect, since the length of coil through which the current flows is increased.

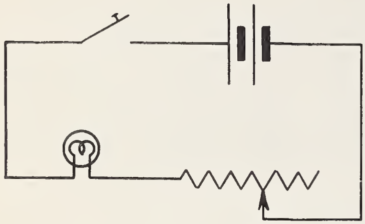


Fig. 36–8. Varying the current through a circuit by means of a rheostat.

Ohm's Law. You have already learned that increasing the voltage applied to a circuit increases the current and that increasing the resistance decreases the current. The relationship of these three quantities—current, voltage, and resistance—is expressed in an equation called *Ohm's Law*, which states that *the current flowing in a circuit is directly proportional to the applied voltage and inversely proportional to the resistance in the circuit.* This law may be written as an algebraic equation:

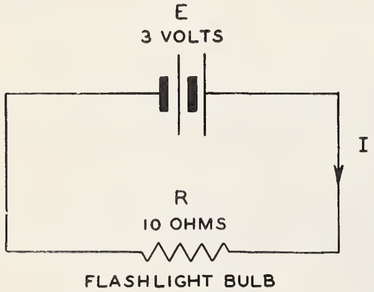


Fig. 36–9. The current in this circuit is determined by Ohm's Law.

current
amp

$$I = \frac{E}{R}$$

- voltage

where I is the current in amperes, E is the voltage applied to the circuit, and R is the total resistance in the circuit.

Let us use Ohm's Law to calculate, for example, the current that flows in a circuit (Fig. 36–9) consisting of two dry cells connected in series and a flashlight bulb whose resistance is 10 ohms. The two cells supply a voltage of 3 volts, so that the current flowing around the circuit and through the bulb is

$$I = \frac{E}{R} = \frac{3}{10}$$

or,

$$I = 0.3 \text{ amperes}$$

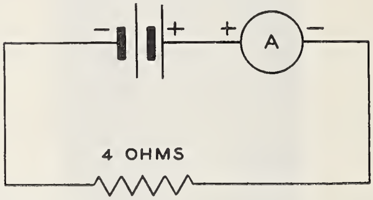


Fig. 36–10. How an ammeter is connected in a simple circuit to measure the current.

Ammeters and Voltmeters. An *ammeter* is an instrument that measures the current in a circuit. *The current is the same at all points in a series circuit,* so the ammeter may be inserted anywhere, but the *positive terminal* must be connected to the *positive* side of the circuit. Fig. 36–10 shows how an ammeter is connected in a circuit with a 4-ohm resistor and a battery.

A *voltmeter* measures the drop in voltage between the points to which it is connected. Let us suppose that a current of 2 amperes, for example, flows through the resistance and that we wish to measure the voltage that forces it through this resistance. We place the voltmeter *across* the resistance, as shown in Fig. 36–11, with its positive terminal connected to the positive side of the circuit.

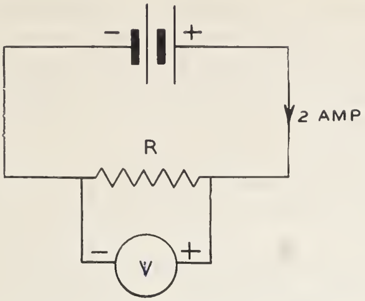


Fig. 36–11. How a voltmeter is connected across the resistance to measure the voltage drop across it.

Let us now examine the voltage and the current in different parts of the circuit we used in Demonstration 36–4.

Demonstration 36–5. Current in a Series Circuit.

Connect two dry cells, a flashlight bulb, switch, rheostat, and ammeter in the circuit shown in Fig. 36–12. Close the switch and record the reading of the meter. Now connect the ammeter on the other side of the rheostat as shown in Fig. 36–13, close the switch, and read the meter again. Now change the setting of the rheostat and note that as the total resistance in the circuit is increased, the current is decreased as we would expect from Ohm's Law.

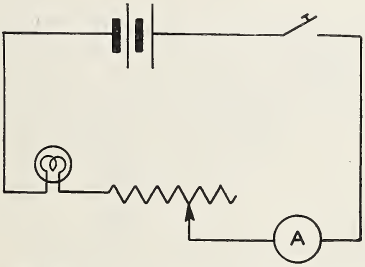


Fig. 36–12. Current in a series circuit.

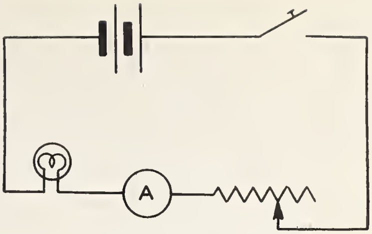


Fig. 36–13. If the position of the ammeter in a series circuit is changed, it indicates the same current. The current at all points in a series circuit is the same.

Notice that, in the first part of this demonstration, the ammeter read the same regardless of where it was connected in the circuit. This, too, is what we would expect, since as many electrons flow out of the rheostat at one end as flow in at the other end; they cannot pile up inside. *At all points in the circuit the current is the same.* In fact, there are no more electrons in the wire when the switch is closed than when the switch is open. When we close the switch we merely provide a conducting path so that the electrons, which are always in the wires and apparatus, may be set in motion by the voltage of the battery.

Although electrical apparatus is not usually connected in series for reasons that will be discussed later in this chapter, many of the strings of colored lights used on Christmas trees are connected in this way, as shown in Fig. 36–14.

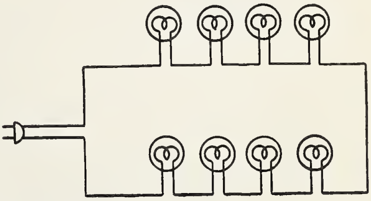


Fig. 36–14. Some Christmas tree lights are connected in series.

One of the disadvantages of series circuits can be seen by examining the diagram. If one bulb in the string burns out, the circuit is opened and all the lights go out. Each bulb must then be tested separately to find the bad one.

Demonstration 36–6. Voltages and Resistance in a Series Circuit.

Using the circuit of Demonstration 36–5, with the rheostat set at about half value, connect the voltmeter across the battery as shown in Fig. 36–15. Read the voltmeter and the ammeter, and use Ohm's Law to calculate the total resistance in the circuit.

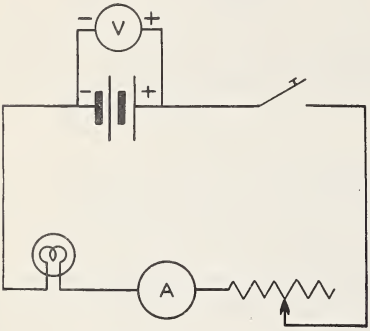


Fig. 36–15. Measuring the voltage provided by a battery in a series circuit.

Connect the voltmeter across the light as shown in Fig. 36–16 and use its reading and the ammeter reading to calculate the resistance of the light. Then connect the voltmeter across the rheostat and in a similar way find its resistance.

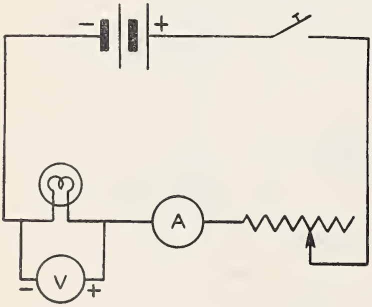


Fig. 36–16. Measuring the voltage drop across a light in a series circuit.

From the data obtained in this experiment you should find that in this circuit (a series circuit) two laws hold true: (1) *The voltage supplied to the circuit by the battery is equal to the sum of the voltage drops around the circuit;* and (2) *the total resistance of the circuit is equal to the sum of the individual resistances.*

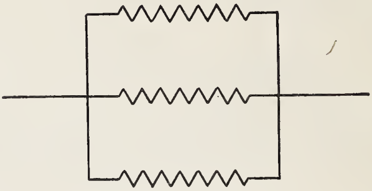


Fig. 36–17. Resistors connected in parallel.

Parallel Circuits. If several resistors are connected in series, the total resistance is equal to the sum of all the resistors. Thus, if three resistors whose resistances are 4, 6, and 5 ohms are connected in a series, their total resistance is 15 ohms. *If resistors are connected in parallel,* however, as in Fig. 36–17, *their total resistance will be less than that of the smallest resistor.* This is so because several paths are provided for the flow of current.

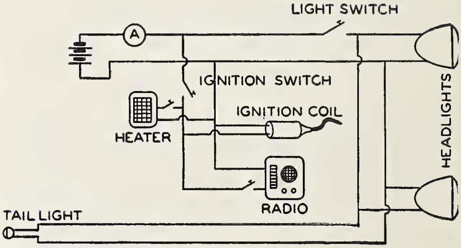


Fig. 36–18. A simplified diagram of an automobile electric system.

An Automobile Circuit. Fig. 36–18 shows in simplified form the electrical circuit of an automobile. You will notice that the lights, radio, heater, and ignition are connected in a parallel circuit to the car battery. The ammeter is placed between the battery and all the rest of the apparatus so that it measures the *total* current being drawn. The ammeter will swing toward "discharge" when the ignition is turned on and current is drawn by the ignition coil. When the light switch is closed, current flows through the headlights and the ammeter shows a greater total discharge current since an additional path for current has been provided through the lights.

In a later chapter we shall see that the lights and appliances in a house-wiring circuit are always connected in parallel.

Cells in Parallel. If all the positive terminals of a group of cells are connected and all the negative terminals are connected, as shown in Fig. 36–19, the cells are said to be in *parallel*. The voltage of a group of cells in parallel is the same as for a single cell, but since each cell supplies only a fraction of the total current, the battery will last longer than a single cell. Batteries in parallel are sometimes useful in starting an automobile. On a cold day the grease and oil may be so stiff that the car battery may be unable to provide enough current to start the car. A second battery, connected in parallel to the first, will usually provide enough additional current to start the engine; it can be disconnected once the engine is running.

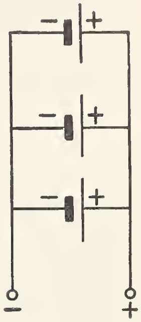


Fig. 36–19. Cells connected in parallel.

current flows from the + to the −
lines of force go from north to south.

THINGS TO REMEMBER

The strength of an electric current is measured in *amperes.*

Voltage is measured in *volts.*

A large voltage may be obtained by connecting several cells in *series* to make a battery.

A battery consisting of cells connected in *parallel* gives the same voltage as a single cell but has a longer life.

Electrical resistance is measured in *ohms.*

The resistance of a wire increases as its length increases.

The resistance of a wire decreases as the area of its cross section increases.

Ohm's Law states:

$$\textit{Current (amperes)} = \frac{\textit{Voltage (volts)}}{\textit{Resistance (ohms)}}$$

or

$$I = \frac{E}{R}$$

QUESTIONS

Jim Kern

A

✓**1.** State Ohm's Law.

✓**2.** Draw the electrical symbol for each of the following: (*a*) cell; (*b*) resistor; (*c*) voltmeter; (*d*) wires crossing, but not connected; (*e*) light bulb.

✓**3.** What is the purpose of an electric cell?

✓**4.** Show by a diagram how a rheostat may be connected in a circuit to control the current through a light bulb.

✓**5.** Describe the construction of a rheostat.

✓**6.** Describe the construction of a dry cell.

7. How is an ammeter connected in a circuit?

8. How is a voltmeter connected in a circuit?

9. Describe the construction of a storage battery.

10. What is meant by the terms (*a*) ampere; (*b*) volt; (*c*) ohm?

11. A 4-ohm, a 6-ohm, and a 12-ohm resistor are connected in series. What is their total resistance? 22 oh

B

12. A 1.5-volt dry cell is connected in a circuit with a 20-ohm light bulb. What current flows through the bulb? .073 amp

13. Two 1.5-volt dry cells are connected in series to a light bulb. An ammeter placed in the circuit shows a current of 0.25 amperes. What is the resistance of the light bulb?

14. A battery forces a current of 2 amperes through an electric bell whose resistance is 5 ohms. What voltage does the battery give?

15. Draw the electrical symbol for each of the following: (*a*) three cells in series; (*b*) rheostat; (*c*) switch; (*d*) three cells in parallel; (*e*) light bulb.

16. Two resistors in series are connected to a 3-volt battery. An ammeter in the circuit reads 0.5 amperes, and a voltmeter connected across one resistor reads 1.0 volt. What is the resistance of the other resistor?

PROJECTS

1. *Examining a Dry Cell.* Get a worn-out radio *B* battery from a radio shop and take it apart. Examine the construction of a single cell and determine how the cells are connected. Are they in series or parallel or in a combination of series and parallel?

2. *Controlling a Light with Double-Throw Switches.* Connect two double-pole, double-throw switches with a battery and a light bulb as shown in Fig. 36–20. This circuit is the kind that is used to control a stairway light so that the light may be turned on and off from either the bottom or the top of the stairs. Each switch controls the light independently of the position of the other. Can you devise a switching method that would control the light in the same way from *three* different positions?

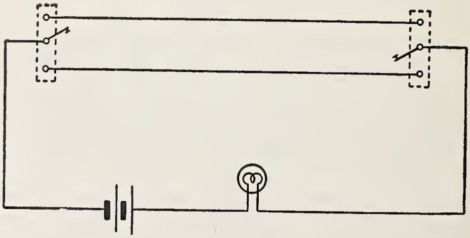
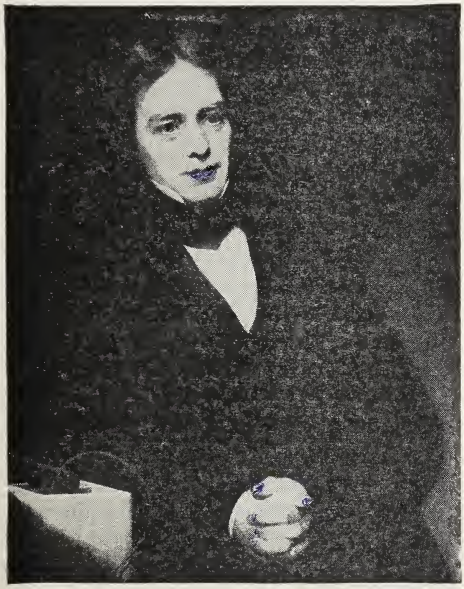


Fig. 36–20. Two switches controlling one light.

Chapter 37

MAGNETISM

In 1831 an English scientist, Michael Faraday, discovered the scientific principle known as *electromagnetic induction*. It proved to be one of the most important discoveries of the 19th century, for it led to the invention of the electric generator by which the energy of coal is converted into electrical energy. The generator is one of the power machines that has made possible our present industrial civilization. This machine depends on the magnetic effect of an electric current. Before describing it, therefore, let us review some of the elementary facts about magnetism.



Courtesy General Electric Co.

Fig. 37–1. Michael Faraday (1791–1867), whose discovery of electromagnetic induction led to the invention of the electric generator.

Magnets. Magnetism was discovered almost three thousand years ago. The Chinese found that small bits of iron would stick to a certain type of stone later called *lodestone*, an ore of iron and the only *magnetic compound* of iron. Lodestones were used to make the first magnets. If one end of a steel needle is rubbed on a lodestone, the needle becomes magnetized and is able to pick up small pieces of iron. Hence, by a magnet we usually mean a magnetized iron or steel bar; that is, a bar that will attract and pick up nails or other pieces of magnetic material. Only a few substances can be magnetized. These include iron and steel, nickel, cobalt, and certain alloys of these metals. Alnico, for example, an alloy of iron, aluminum, nickel, and cobalt, is one of the strongest magnetic materials known.

If we place a magnet on a cork floating on water, we notice that the magnet turns so that one end of it points toward the north. If we mark this end with a piece of chalk and set the magnet in a different direction, we observe that as soon as it is free to move, it again turns to the north. The end that seeks the north is called the *north pole* of the magnet; the other end is called the *south pole*. All magnets have a north and a south pole.

A magnet that indicates north-and-south directions is called a *compass*. The first compass used by sailors was the floating type described above. Another interesting thing about magnets is that magnetic poles affect each other as shown by the following demonstration.

Demonstration 37–1. Magnetic Attraction and Repulsion.

Arrange two compasses some distance apart. When they have stopped swinging, lift one off its pivot and bring its north pole near the north pole of the other compass. Notice that the north poles push each other away. Now bring the south poles together and note that the south poles also push each other away. Then bring the north pole of one compass toward the south pole of the other and notice that these poles attract each other.

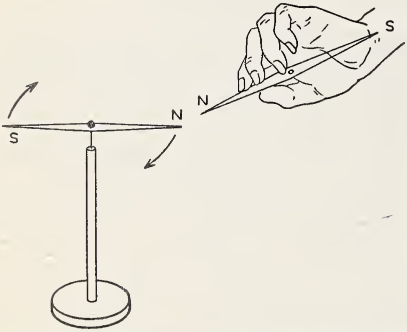


Fig. 37–2. Like magnetic poles repel each other.

From this demonstration we can discover an important magnetic law. How would you summarize your observations? Actually we state the law briefly: *Unlike poles attract; like poles repel*. Notice that this law is similar to the law of electric charges that was stated in Chapter 35.

Magnetic Fields. If a small compass is placed near a magnet, it will be deflected from its normal north-south direction. Fig. 37–3 shows how a compass points when placed in different positions close to a magnet. It is often important to know in what direction the magnetic force acts. Fig. 37–4 gives this information for a straight bar magnet. The long curved lines between the two poles are called *magnetic lines of force;* all the magnetic lines together constitute the *magnetic field* of the magnet. If a small compass is placed close to the magnet, it will point along the line of force where the center of the needle is located, as shown by comparing Figs. 37–3 and 37–4. Hence these lines of force show the direction in which the magnetic force of the magnet acts at any point in the field. This field can be checked more carefully by the following demonstration.

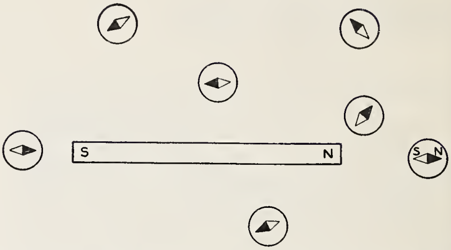


Fig. 37–3. The direction in which small compasses will point when at different places close to a bar magnet.

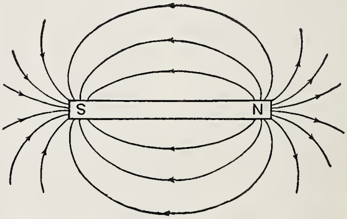


Fig. 37–4. Field about a bar magnet.

Demonstration 37–2. The Magnetic Field About a Bar Magnet.

Sprinkle iron filings as evenly as possible over a large piece of cardboard or glass. Carefully place the cardboard over a bar magnet and tap it gently. You will see the filings arrange themselves in long ridges resembling the lines of magnetic force in the field about a bar magnet as shown in Figure 37–4.

Repeat this procedure using a horseshoe magnet or two bar magnets arranged first with like poles about an inch apart and then with unlike poles about an inch apart. You will notice that in every case the lines go from a north pole to a south pole, never from a north pole to a north pole or from a south pole to a south pole.

The Earth as a Magnet. Not all magnets, however, are in the shape of a bar or a horseshoe. The earth, for example, is spherical; yet it is a large magnet. Scientists cannot satisfactorily explain why the earth is magnetized. It behaves like a bar magnet with a *south magnetic* pole in the Arctic close to the *geographical North Pole*, and a *north magnetic* pole in the Antarctic. This is understandable if we consider the law of magnetic poles. The pole of a compass that points toward the Arctic is called the *north* magnetic pole; therefore, the pole in the Arctic must be a *south* magnetic pole. Fig. 37–6 shows the earth as a magnet. Lines of force start at one pole and end at the other. These constitute the *magnetic field* of the earth. The north pole of a compass will therefore point in the direction of the arrow on the line.

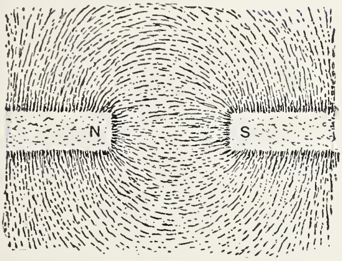


Fig. 37–5. Iron filings show the magnetic field between unlike poles of two bar magnets.

Magnetic fields are not limited to magnets, however. *They are always present around electric currents,* as shown by the following demonstration.

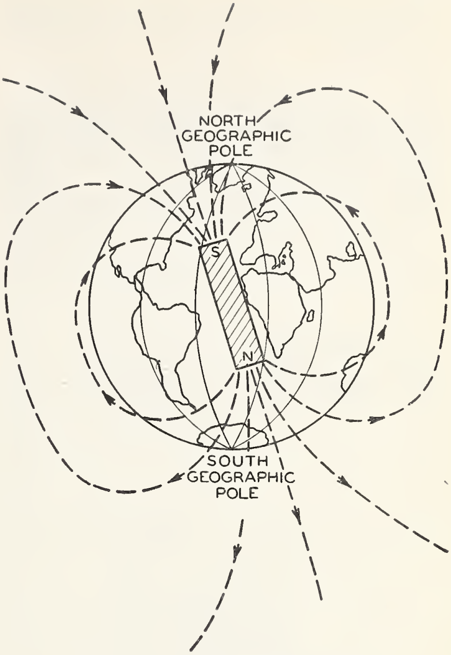


Fig. 37–6. The earth as a magnet.

Demonstration 37–3. Magnetic Field About a Current.

Arrange a battery, a switch, and a wire about six feet long as shown in Fig. 37–7. Place a compass near the wire and hold the wire parallel to and *above* the compass needle. Close the switch and notice that as soon as the current flows the needle is deflected. What does this indicate?

Now hold the wire *under* the compass and

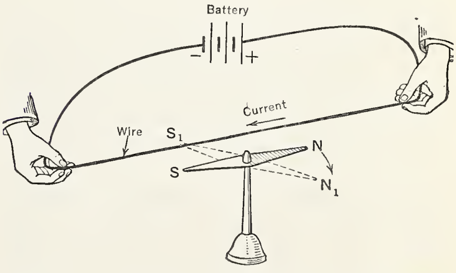


Fig. 37–7. A wire carrying a current shows a magnetic effect.

close the switch. Notice that this time the deflection is in the opposite direction. What does this indicate?

This demonstration shows that there is a magnetic effect, or a *magnetic field around an electric current*. The field is a series of concentric circles about the wire, as shown in Fig. 37–8 (*a*). If in the above demonstration the current is reversed by reversing the connections of the wires to the battery, we find that the deflection of the needle is also reversed. This can only mean that the magnetic field is reversed, as shown in (*b*).

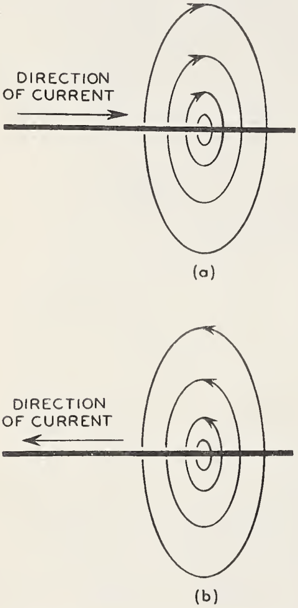


Fig. 37–8. The direction of a magnetic field about an electric current carried in a wire.

Electromagnets. An electromagnet, unlike the permanent magnet used in compasses, can be made to lose or gain magnetism at will. Let us make an electromagnet and discover some of its properties.

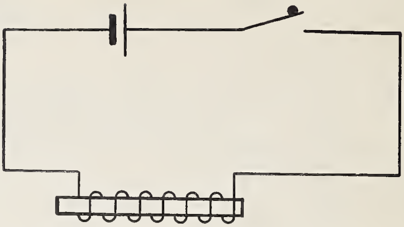


Fig. 37–9. Circuit of an electromagnet.

Demonstration 37–4. To Make an Electromagnet.

Wind about fifty turns of insulated copper wire (No. 18 cotton-covered bell wire is satisfactory) around a large soft iron rod. Connect the ends of this coil to a circuit containing a switch and a dry cell, as shown in Fig. 37–9. Hold the end of the rod over a few small nails or bits of iron and close the switch. Some nails are attracted to the end of the rod. Then open the switch and some of them fall from the rod.

When a current flows through the coil, therefore, the iron rod becomes magnetized by the magnetic field of the current, but as soon as the switch is opened the rod loses most of its magnetism.

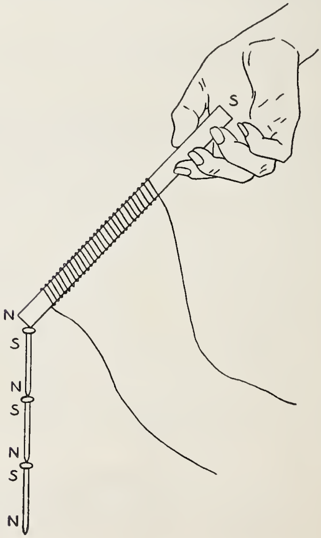


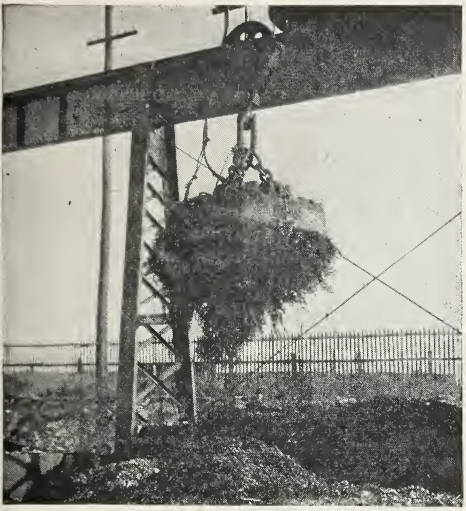
Fig. 37–10. Magnetic induction.

Hi

Demonstration 37–5. The Poles of an Electromagnet.

Bring one end of the rod near the north pole of a compass and close the switch. If the north pole of the compass is repelled, the near end of the rod is, of course, the north pole of the electromagnet; if it is attracted, this end is the south pole of the electromagnet. Reverse the connection to the battery so that the current flows in the opposite direction and you will find that the magnetic poles of the rod are reversed.

Now support a single nail from the end of the electromagnet. Next support another nail from the end of the first nail, and then support a third nail from the end of the second, and so on until a long string of nails is suspended from the magnet as shown in Fig. 37–10.



Courtesy General Electric Co.

Fig. 37–11. A large lifting magnet picking up 850 pounds of machine shop steel turnings.

The last nail on the string is a long distance from the pole of the electromagnet. How, then, is it held up? It is held because magnetism is *induced* from one nail to the next. The first nail becomes magnetized by being in the magnetic field of the electromagnet; its polarity is shown in Fig. 37–10. The field of this nail then magnetizes the second nail, and so on down the string. Thus, a piece of magnetic material which is not normally a magnet has become magnetized temporarily by *magnetic induction.*

Electromagnets have numerous uses. Electric motors, bells, radio loud-speakers, telephones, and many other electrical appliances contain one or more electromagnets. Very large electromagnets are used in some industrial plants for transporting from one position to another heavy iron objects such as scrap iron and railroad rails. For this purpose the electromagnet is usually attached to the end of a derrick; a heavy current flowing through the coil supplies the strong magnetic field needed for lifting (see Fig. 37–11).

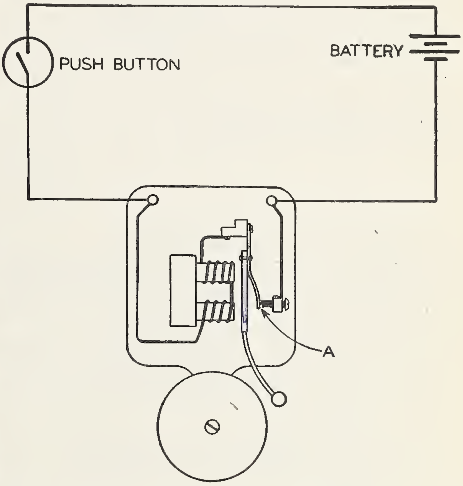


Fig. 37–12. The circuit and construction of an electric bell.

The Electric Bell. Fig. 37–12 illustrates the construction and wiring of an electric bell. The small soft iron *armature,* to which the clapper is fixed, is normally held in the position shown in the diagram by the spring action of the strip of spring steel that supports it. When the switch is closed (the button is pushed), the current flows through the coils (energizing the magnet), through the contact point at *A* on the armature, and back to the battery.

The instant the magnet is energized it attracts the armature and pulls the clapper against the bell, causing it to ring. At the same time, as soon as the armature moves toward the magnet, the electric circuit is broken at the contact point *A*, and the current ceases to flow. The magnet thus loses most of its magnetism, and the armature is made to fly back by its spring support. Contact is made again at *A* and the current flows again. The armature is again attracted by the magnet, ringing the bell, and the process is repeated, and the bell continues to ring as long as the button is pressed. In some electric buzzers (an electric bell without clapper or bell) the armature flies back and forth several hundred times a second.

THINGS TO REMEMBER

The *north pole* of a magnet points to the north when the magnet is free to turn.

Every magnet has both a north and a south pole.

Like magnetic poles *repel* each other and *unlike* poles *attract* each other.

A *magnetic compass* is essentially a small bar magnet that is free to rotate.

A *magnetic field* is always present in the region of electric currents.

An *electromagnet* consists of a coil of insulated wire wound about a soft iron core.

QUESTIONS

A

1. State the law of magnetic poles.

2. Determine which of the following statements are true and which are false. Then correctly reword the false ones.

(*a*) The earth's magnetic pole in the Arctic is a *south* magnetic pole.
(*b*) Like poles attract, and unlike poles repel.
(*c*) The earth has a magnetic field.
F (*d*) Electromagnets are permanent magnets.

3. What is a magnetic compass?

4. What is a horseshoe magnet?

5. Describe an experiment that shows that like poles repel and unlike poles attract.

B

6. Why do we say the earth has a *north* magnetic pole in the Antarctic?

7. Draw a sketch of the field about a bar magnet.

8. Describe an experiment by which the magnetic field about a bar magnet can be plotted.

9. Name three kinds of electric devices that use electromagnets.

10. Explain how you would make an electromagnet.

PROJECTS

1. *Plotting the Magnetic Field about a Bar Magnet.* Place a bar magnet on a large sheet of paper. At one corner of the north pole place a small compass. Make a dot on the paper with a pencil as close to the north pole of the compass as possible. Move the compass until its south pole is as close as possible to the dot that previously marked its north pole as shown in Fig. 37–13. Now make another dot close to its north pole. Move the compass again so that its south pole points to the new dot. Keep repeating this process until the compass has reached the south pole of the magnet. Connect all the dots with a smooth line. This line should be a loop similar to one of the lines in Fig. 37–4 Obtain another line of force in the same manner, starting at the other corner of the

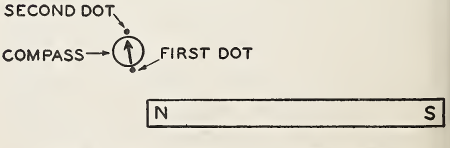


Fig. 37–13. Plotting a magnetic field.

north pole of the magnet. This should give you a similar loop on the other side of the magnet. Obtain three or four lines on each side, starting each line a little farther away from the pole and closer to the center of the magnet. Also trace a line starting from the exact center of each pole, using the same method. All these lines together should give a reasonable reproduction of the magnetic field about a bar magnet as shown in Fig. 37–5.

2. *To Photograph a Magnetic Field.* Permanent pictures can be made of the fields obtained with iron filings in Demonstration 37–2 by doing the demonstration in a dark room and using blueprint paper instead of cardboard. After the pattern is obtained, carefully lift the paper from the magnet so as not to disturb the pattern, and expose the paper to the sunlight for about 15 minutes; then wash it in water and dry it. This will give a permanent picture of the field.

Chapter 38

ELECTRIC POWER

Electromagnetic Induction. The discovery that a current produces a magnetic field gave rise to a far more important question: Can magnetism produce an electric current? As already stated, Faraday discovered that magnetism can cause or induce a current by *electromagnetic induction.* The following demonstration is similar to the one performed by Faraday when he generated the first electric current by means of a magnetic field.

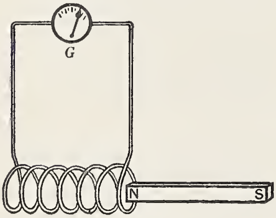


Fig. 38–1. Inducing a current in a coil by means of a moving magnet.

Demonstration 38–1. To Generate an Electric Current in a Coil by Means of a Moving Magnet.

Make a coil of several hundred turns of fine insulated wire on a cardboard mailing tube. Connect the ends of the coil to the terminals of a galvanometer, an instrument that shows the presence of an electric current. Now quickly thrust one end of a bar magnet *in* and then *out* of the hollow coil. What happens? Hold the magnet stationary inside the coil. Does the galvanometer show any electric current when the magnet is stationary? Does the current flow in the same direction when the magnet is pulled out as when it is pushed in? Try moving the coil instead of the magnet. Does it make any difference whether the magnet or the coil is moved?

From this experiment we may conclude that *a current is induced in a coil when the magnetic field in the coil is changing; and that the direction of the current depends on the direction of the motion of the magnet or coil.* This demonstration also illustrates the essential features of a dynamo, or generator.

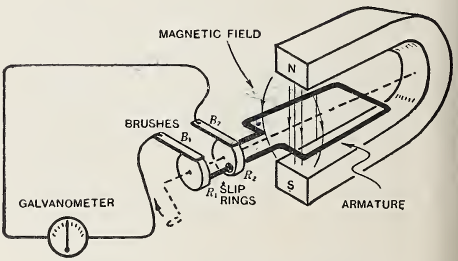


Fig. 38–2. A simple AC generator.

Electric Generators. *An electric generator is a machine that converts mechanical energy into electrical energy.* It has two main parts, an *armature* and a *magnetic field.* The *armature* consists of many coils of insulated wire supported on a shaft that revolves in a magnetic field. Magnets are fixed to the frame of the generator and produce a magnetic field through the armature coils. Some form of mechanical power, usually a steam turbine, is used to turn the armature at high speed.

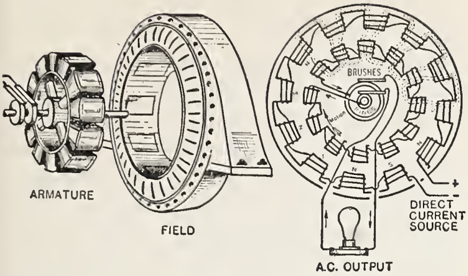
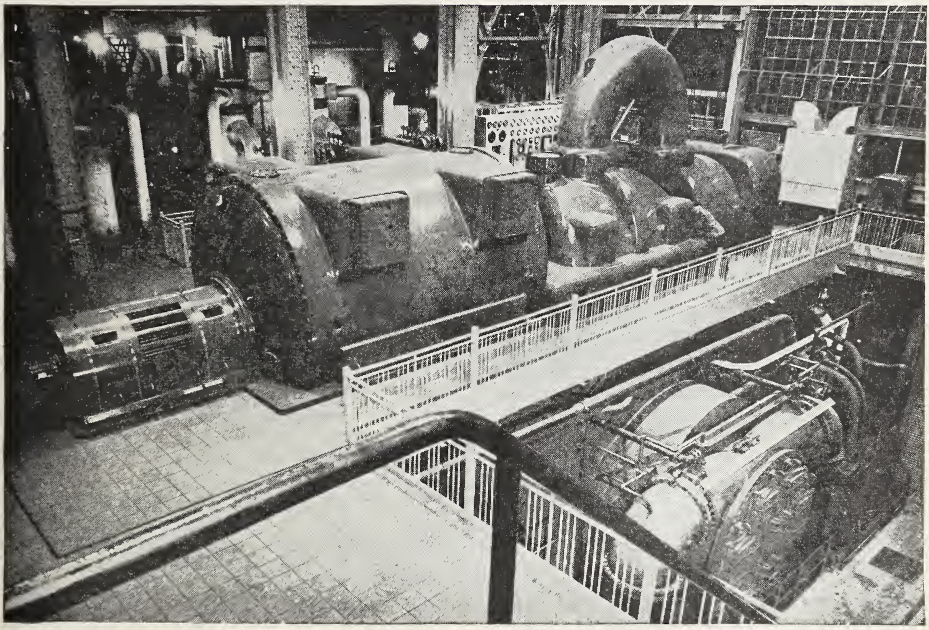


Fig. 38–3. A commercial AC generator.

As it revolves, its coils move past the stationary field magnets and an electric current is generated in the coils, just as in the coil of Demonstration 38–1. Notice, however, that in this generator the magnets are fixed and the coils move, whereas in the demonstration the coil was fixed and the magnet moved. The current is led from the armature by carbon contacts, called *brushes*, and is carried by wire to the place where it is to be used. A simple generator of this type is shown in Fig. 38–2.

In large generators the current is induced in fixed coils on the frame, called the *stator*, while a rotating field that cuts these coils is produced by sending a small current through brushes to electromagnets mounted on the rotating shaft, called the *rotor*. This is done because the field current in the rotor need be only very small and thus causes little sparking and heat at the brushes. It is obtained from a small generator called an *exciter*. The current induced in fixed coils, on the other hand, represents the total power output. In a large generator the current is so great that, if it

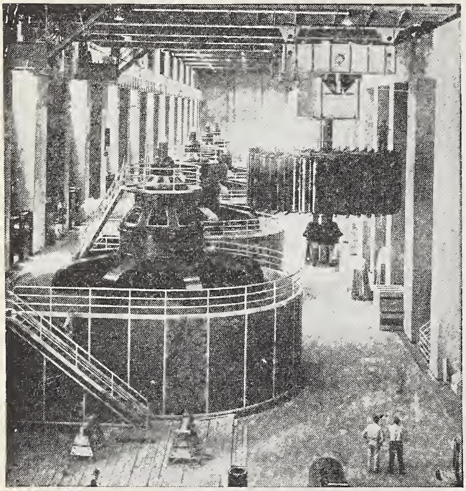


Courtesy Westinghouse Corp.

Fig. 38–4. A steam-turbine generator set. On the extreme left is the exciter. Then comes the large AC generator, and on the right is the steam turbine. The condenser for the turbine is visible on the floor below, directly beneath the turbine.

were induced in the rotor, it would produce excessive sparking and heat at the brushes, and would therefore rapidly wear them away.

Generators that supply cities and factories with light and power are enormous, costly, and complicated machines (see Fig. 38–4). Rotating shafts of steam turbines are connected directly to the rotating shafts of the large generators. In this way electric energy is generated from the energy of burning coal that drives the turbines.



Courtesy General Electric Co.

Fig. 38–5. Hydroelectric power station at Hoover Dam. Four vertical 16,500 volt generators, each producing about 80,000 kilowatts of electric AC power can be seen. The shafts of these generators are mounted vertically and connected to huge water turbines that are beneath the floor and not shown in the picture. Note the large revolving field from one of these generators suspended from a crane. The operation of the water turbines that turn these generators is discussed in Chapter 31.

Every automobile has a small generator that provides electricity for the ignition, lights, heater, and radio when the engine is running. The engine turns the armature of the generator, which, in turn, supplies the current. The generator also recharges the storage battery, which supplies electricity to start the motor.

Electricity in Industry. About 1910 electricity became a major aid to industry. It enabled factories to use the power of distant waterfalls. Electricity obtained when water power is used to turn the rotors of large generators is called *hydroelectric power.* The water flows down pipes where it drives a water turbine whose shaft turns the rotor of a generator.

The tremendous mechanical energy of the water flowing over Niagara Falls was one of the first sources of water power for the large-scale production of electricity. In recent years huge dams have been built, and the energy of the stored-up water is used to generate thousands of kilowatts of electric power.

There is still much unused water power in the United States. Nearly every mountain stream could be dammed up to provide electric power. But the initial expense of building a huge dam is large, whereas coal is a comparatively cheap source of power. It is therefore not always economical to use water power to provide electrical energy. Once a dam is built, however, it serves other purposes besides generating electricity. For instance, it prevents damage by spring floods; and in dry climates it provides irrigation to make the land fertile.

Mountainous countries, such as Switzerland and Norway, are ideal for generating hydroelectric power. There electricity is abundant and cheap.

Alternating Current. The current generated by the type of generator shown in Fig. 38–2 is an *alternating current;* that is, a current which flows first in one direction, and then reverses and flows in the opposite direction. In the large alternating-current generators, called *alternators,* this process is repeated 120 times per second. To see why such generators produce an alternating current, let us recall that in Demonstration 38–1 the direction of the induced current depended on the direction of the motion which caused that current. The revolving rotor of a generator has the same effect, that is, the direction of motion of the wires in a single loop of the armature that cuts the field produced by the stator, changes every half-revolution.

Transformers. A *transformer* consists of an iron core on which are wound two coils of wire, called the *primary* and the *secondary*. Usually the number of turns on the coils is different. If the number on the secondary is greater than that on the primary, the transformer is a *step-up* transformer. It increases the voltage. If the number of turns on the secondary is less than that on the primary, it is a *step-down* transformer. It reduces the voltage.

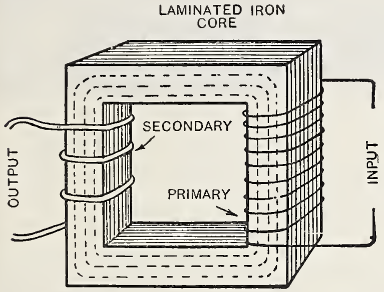


Fig. 38–6. A step-down transformer.

Fig. 38–6 shows the construction of a transformer. When an alternating current flows in the primary, the changing magnetic field produced in the iron core induces a voltage in the secondary. The ratio of the voltage induced in the secondary to the voltage applied to the primary is the same as the ratio of the number of turns on the secondary to the number of turns on the primary. In mathematical form this is expressed as follows:

$$\frac{\text{Volts in secondary}}{\text{Volts in primary}} = \frac{\text{Turns on secondary}}{\text{Turns on primary}}$$

It is also true that,

$$\frac{\text{Current in secondary}}{\text{Current in primary}} = \frac{\text{Turns on primary}}{\text{Turns on secondary}}$$

For example, suppose that a transformer has 2,000 turns on its secondary and 500 turns on its primary. If 110 volts are applied to the primary, the voltage produced in the secondary can be found as follows:

$$\frac{\text{Voltage in secondary}}{110} = \frac{2000}{500}$$

$$\therefore \text{ Voltage in secondary} = \frac{2000 \times 110}{500} = 440 \text{ volts}$$

Let us now find the secondary current if the primary current is 80 amperes.

$$\frac{\text{Current in secondary}}{80} = \frac{500}{2000}$$

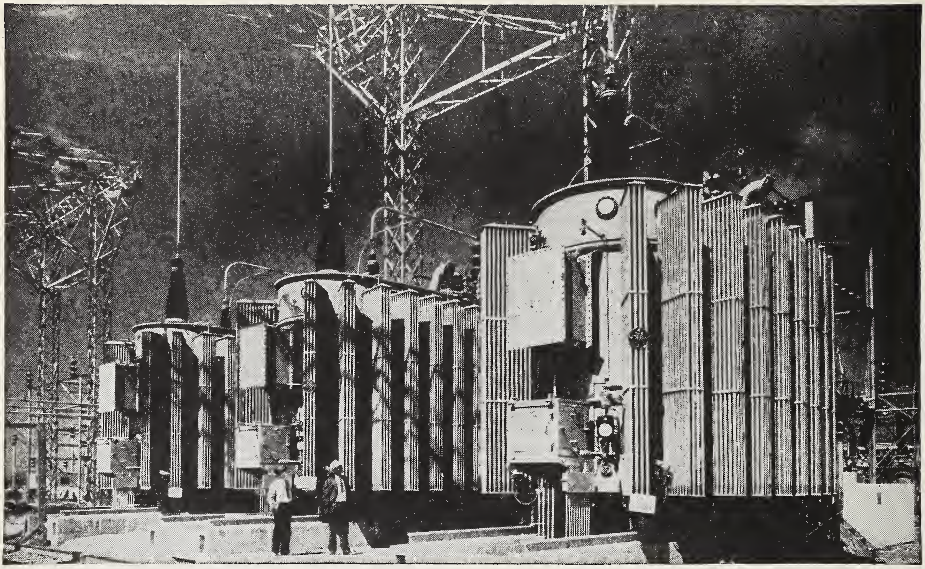
$$\therefore \text{ Current in secondary} = \frac{500 \times 80}{2000} = 20 \text{ amperes}$$

Thus we see that this step-up transformer has *raised the voltage* from 110 volts to 440 volts and *decreased the current* from 80 amperes to 20 amperes.

Electric energy is often transported over long distances by overhead wires called *transmission lines* or *power lines*. For this purpose alternating current is used. By means of a transformer the voltage produced by, say, a 10,000-volt alternator can be stepped up to over 100,000 volts. When the voltage is increased, the current is correspondingly reduced. The smaller the current, the lower the power loss along the transmission lines.

Transformers may *step down*, or reduce, voltage. Step-down transformers are used at the end of a long transmission line to step the high voltage down to 110 volts, which is safe and practical for most purposes.

A Direct-Current Generator. The small generators called exciters which provide current for the rotating field of a large alternator must be direct-current generators so that the field in the rotor of the large generator will always be in the same direction. A DC (di-



Courtesy General Electric Co.

Fig. 38–7. Three large step-down transformers capable of handling nearly 33,000 kilowatts of power. These transformers step down 230,000 volts from a transmission line to 13,800 volts for local distribution. Such step-down transformers and their associated equipment make up what is called a "substation."

rect current) generator differs from the simple AC (alternating current) generator in the method employed to lead the induced current from the armature to the brushes. The connection from the ends of the armature coil to the brushes must be reversed every time the current induced in the armature changes direction, so that the current flowing through the brushes is always in the same direction. This is done by a *split-ring commutator.*

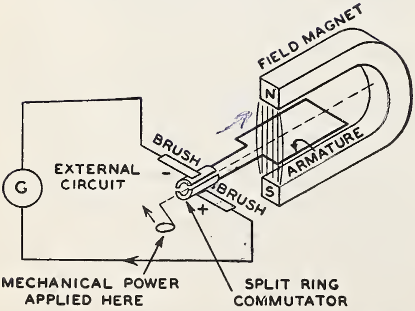
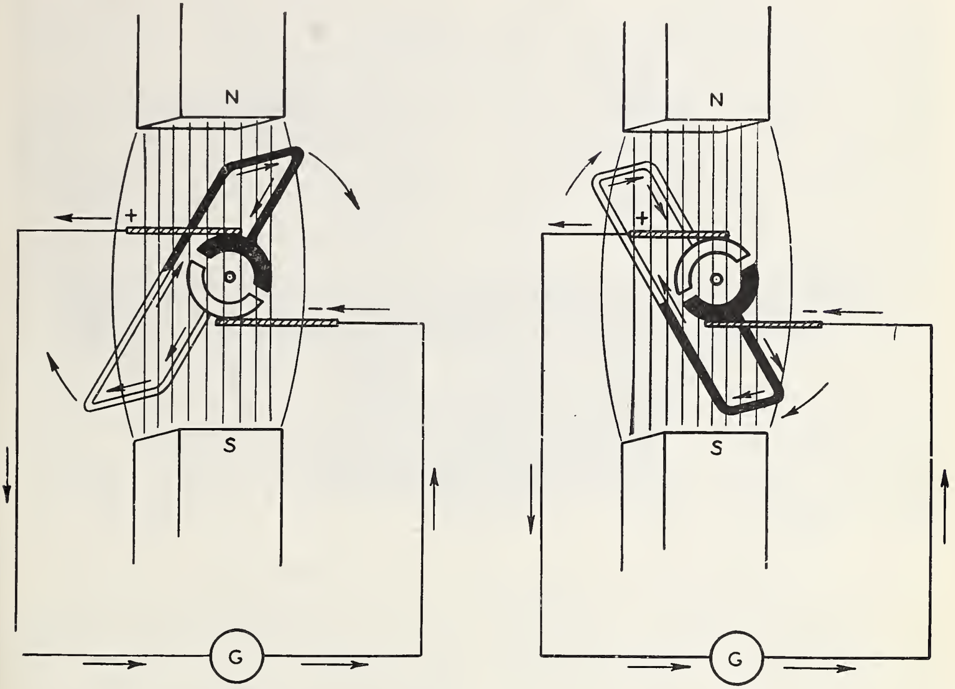


Fig. 38–8. Simplified diagram of a DC generator.

To see how the split-ring commutator works, let us assume that the armature is in the position shown in (*a*) of Fig. 38–9 and that the current is flowing in the armature and through the brushes in the direction shown. When the armature reaches the position shown in (*b*), the current induced in it will be in the opposite direction; but the connection of the ends of the armature coil to the brushes is also reversed by the action of the two insulated commutator segments rotating with the shaft. These split-ring commutator segments must, of course, be correctly placed with respect to the armature coil so that the switching of each, from one brush to the other, takes place the instant the direction of the current changes in the armature. We also see from Fig. 38–9 that the output current is always in the same direction, though it is a pulsating rather than a steady current. In practice, DC generators have many armature coils and many pairs of commutator segments arranged in succession about the armature, thus producing a much steadier current.



(a) (b)

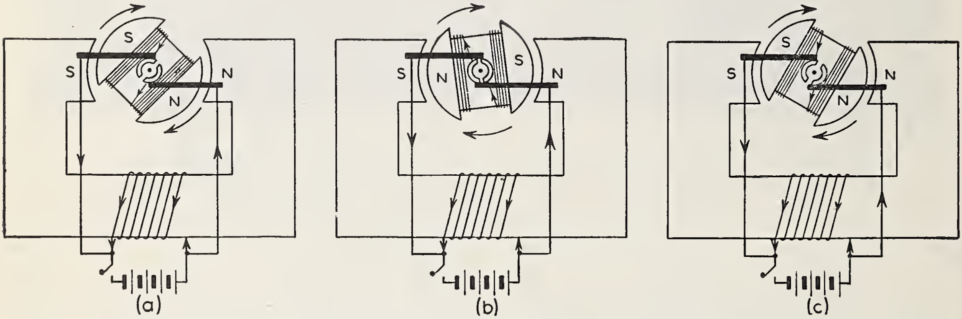
Fig. 38–9. Action of the commutator in a DC generator.

DC generators are used for charging batteries, in refining copper, in the manufacture of aluminum and magnesium, in electroplating, and for other purposes when a direct current is necessary.

Electric Motors. The electric current generated by a dynamo can also be led into a machine to produce mechanical energy. Such a machine is called a *motor.* In principle a generator and a motor are similar, but in the tasks they perform they are quite different. *A generator converts mechanical energy into electrical energy; a motor converts electrical energy into work, or mechanical energy.* When we say that electricity runs a lathe, a pump, a vacuum cleaner, or a refrigerator, we really mean that electric power is supplied to a motor which works these machines.

How does an electric motor run? The diagram in Fig. 38–10 shows that in design the electric motor resembles a simple DC generator. It differs from the generator in one respect, however. Instead of a permanent field magnet to provide the field for the armature, the motor has an electromagnet.

A current is fed to the rotating armature of the motor through two brushes and a split-ring commutator. Now let us assume that when the switch is closed the armature is in position (*a*) of Fig. 38–10. Current flows through the field coil in a direction that gives the U-shaped field magnet the polarity shown in (*a*). The current also flows through the brushes and through the split-ring commutator in a direction that gives the armature (also an electromagnet) the polarity shown. Obviously the two adjacent south poles will repel each other, causing the armature to rotate in a clockwise direction until it reaches position (*b*) of Fig. 38–10. In this position each brush is about to change contact from one segment of the split ring to the other. The two split-ring segments are mounted directly on the armature shaft (but insulated from it and from each other) and so rotate with the shaft. This change serves to reverse the direction of flow of the current around the armature and hence the polarity of the armature to that shown in (*c*) of Fig. 38–10. The armature will therefore continue to rotate in a clockwise direction instead of being pulled back, as would have been the case if its polarity had not been changed at the proper point. When the armature has rotated through another 180 degrees from the position shown in (*c*), the polarity is again changed to keep it rotating in a clockwise direction. This type of motor is often called a *universal* motor, since it can operate on either AC or DC.



(a) (b) (c)

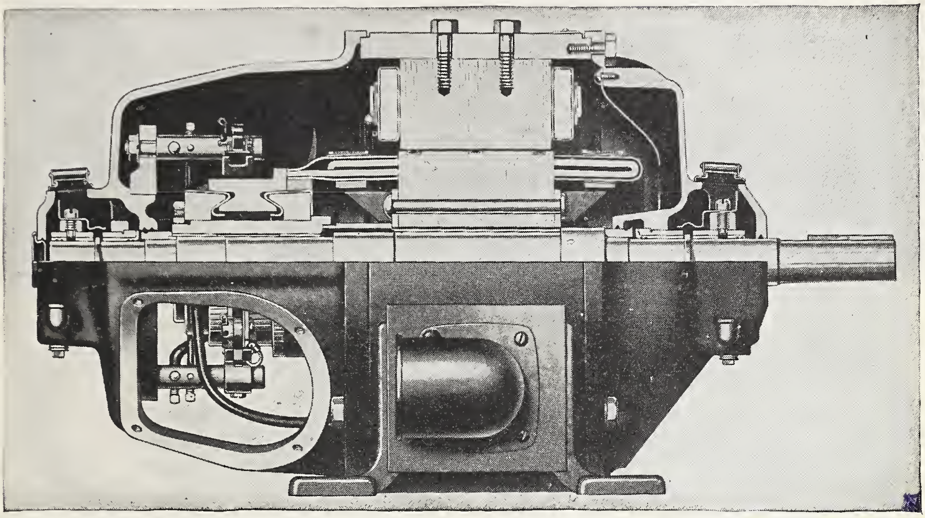
Fig. 38–10. The action of the commutator in an electric motor.

Large modern electric motors, like DC generators, usually have many separate armature coils and commutator segments, but their manner of operation is much the same as that of the simple motor. Some AC motors work on different principles from the one described here, but the details of their operation are quite complicated.

Advantages of Electric Power. As a source of mechanical power, electricity is especially convenient. Electric motors have many advantages over steam engines or internal-combustion engines.① They are cleaner to operate, as they need no dirty or messy fuel.② They require only wires to carry invisible electric power. Unlike gasoline motors, electric motors③ do not give off unpleasant exhaust gases, and they④ operate with much less noise and vibration. Moreover, they⑤ do not become extremely hot.

Electric Locomotives. Sometimes large electric motors which get their electric energy from overhead wires are used instead of steam engines in railroad locomotives. Electric locomotives are much easier to control than steam locomotives and produce no smoke or dirt.

The Diesel-electric locomotive, however, does not even need overhead wires. In this type of engine fuel oil is burned in a Diesel engine, and the mechanical power from the crankshaft of this engine rotates the armature of an electric generator. The electric power produced by this generator is then used to run the electric motors which turn the drive wheels of the locomotive and pull the train. This seems an unnecessarily long and wasteful series of steps in converting the energy of fuel oil into the mechanical energy that runs the train, but Diesel-electric motors are more easily controlled than Diesel locomotives.



Courtesy General Electric Co.

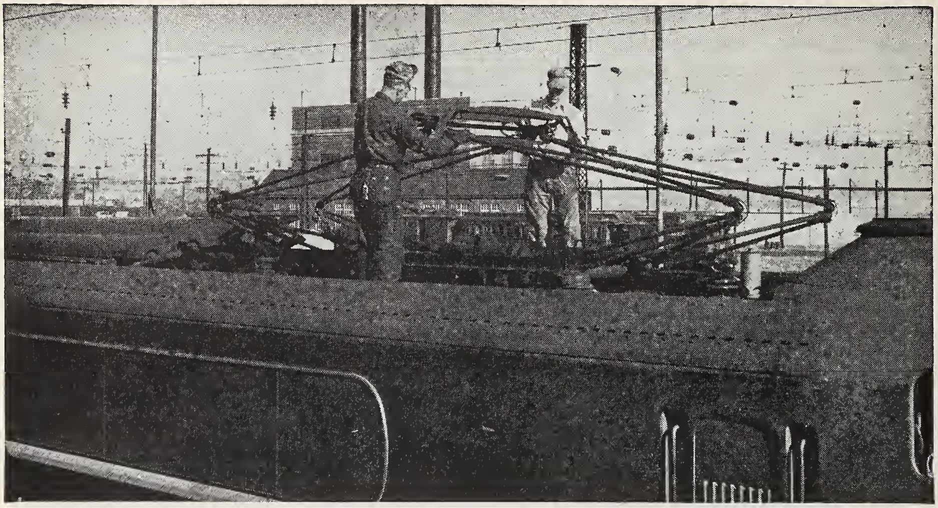
Fig. 38–11. A partially cut-away view of a heavy duty DC motor. The commutator and brushes can be seen near the left-hand end. The rotating armature is mounted on the shaft that projects from the right end. This shaft rotates with the armature and delivers the power of the motor through pulleys and belts or gears to the machine it runs. The fixed iron core on which the field coils are wound is shown just above the armature core fastened to the top of the frame by the two large bolts.

Electric Power and Energy. Electric motors and generators, like other machines that use energy, are often rated in terms of their *power*. Electrical devices are usually rated in terms of *watts* rather than horsepower. *A watt is the product of the voltage applied to an electrical device and the current that flows through it.* Or,

Power (watts) = Voltage (volts) × Current (amperes)

For example, a light bulb that operates on 110 volts and draws $\frac{1}{2}$ ampere of current consumes electric energy at a rate of $110 \times \frac{1}{2}$, or 55 watts.

Because most motors are rated in horsepower, we sometimes want to convert watts to horsepower. To do this, we should know that 746 watts are equivalent to one horsepower; or that one *kilo*watt (1,000 watts) is equal to 1.34 horsepower. Hence, if a single horse were used to turn the armature of a generator to provide electric light, he would be able to keep about seven 100-watt lamps burning.



Courtesy The New Haven Railroad

Fig. 38–12. A device called a pantograph, mounted on the roof of an electric locomotive, can be raised to make electric contact with the overhead wire to provide a closed circuit from the wire, through the electric motors in the locomotive, to the rails and back to the power station.

Electric energy, on the other hand, is measured, not in foot-pounds or mile-tons, but in a more convenient unit, the *kilowatt-hour*. (One kilowatt hour is equal to 2,640,000 foot-pounds.) Thus if a motor with a power of 2 kilowatts runs for 8 hours, it consumes 2 × 8, or 16, kilowatt-hours of electric energy. When electricity is sold to the consumer, it is the electric *energy* used that is paid for. To measure this energy, a *watt-hour meter* is in-

Courtesy New York Central System

Fig. 38–13. A Diesel-electric passenger locomotive consisting of two separate units of 2,000 horsepower each.

Courtesy The New Haven Railroad

Fig. 38–14. A heavy duty Diesel-electric locomotive hauling a loaded freight train.

stalled in every building supplied with electricity.

If in your community one kilowatt-hour costs 5 cents, what will it cost to run seven 100-watt lamps for eight hours? The number of kilowatt hours $= 7 \times 100 \times \frac{8}{1000}$, or 5.6. Therefore the cost will be 5.6 × 5, or 28 cents.

THINGS TO REMEMBER

Faraday discovered that a changing magnetic field about a coil of wire induces a current in the coil. This is called *electromagnetic induction.*

An electric *generator* converts mechanical energy into electric energy.

A *simple AC generator* contains a *field magnet,* an *armature, slip rings,* and *brushes.*

A *DC generator* must contain a *split-ring commutator.*

An *electric motor* converts electric energy into work.

A *simple electric motor* consists of a *field electromagnet,* an *armature,* a *split-ring commutator,* and *brushes.*

Electric power is measured in *watts.*

Power in *watts* is equal to the *current* multiplied by the *voltage.*

One *horsepower* equals 746 *watts.*

Electric energy is measured in *kilowatt-hours.*

QUESTIONS

A

1. Name a device that changes electrical energy into motion.

2. What are three advantages that electric motors have over gasoline engines?

3. List at least four ways in which electric motors can be used in a household.

4. What is a watt?

5. What is a kilowatt?

6. How is power in watts calculated?

7. Name the important parts of an electric generator.

8. Name the important parts of an electric motor.

9. What is a Diesel-electric locomotive?

10. How much electrical energy is used by a 100-watt light bulb that burns for 24 hours?

11. Determine which of the following statements are true and which are false. Then correctly reword the false ones.

- (*a*) Electric energy is usually measured in foot-pounds.
- (*b*) Electric power is usually measured in watts.
- (*c*) A generator converts electrical energy into mechanical energy.
- (*d*) The split-ring commutator in a motor serves to reverse the direction of the current flowing through the armature.
- (*e*) The brushes of a generator are small permanent magnets.

12. Describe the construction of a transformer.

13. A step-up transformer with 2,000 secondary turns and 100 primary turns has a voltage of 500 volts across its primary. What voltage is induced in the secondary?

B

14. How is electricity obtained from coal?

15. How is electricity obtained from water?

16. Describe how to generate an electric current using a coil of insulated wire, a galvanometer, and a bar magnet.

17. An electric motor produces 20 horsepower. How many watts of electric power does it use? 746 × 20 : 14,920 watts.

18. How many watts are used by an electric motor that lifts a 3,000-pound elevator to the top of a 330-foot building in two minutes? 11,190 watts

19. Describe the operation of an electric motor.

20. How much does it cost to run a $\frac{1}{4}$-horsepower motor for five hours if electric energy costs 12 cents per kilowatt-hour?

21. How does a DC generator differ from an AC generator?

22. Why is the electric current generated in a large alternator taken from the stator rather than the rotor?

23. A transformer is supplied with 100 volts at 10 amperes on its primary and delivers a current of $\frac{1}{2}$ ampere from its secondary. What voltage is supplied by the secondary?

PROJECT

Visiting an Electric Power Plant. The operators of power stations are usually glad to show visitors around. Organize a group and make arrangements for the visit. Some of the important things to look for are:

- (*a*) the coal-feeder system
- (*b*) the boilers
- (*c*) the condensers
- (*d*) the steam turbines
- (*e*) the alternators
- (*f*) the exciter for producing a magnetic field
- (*g*) the switchboard
- (*h*) the transformers

In visiting the plant remember that high-pressure steam, rapidly rotating machinery, and the high voltage in exposed wiring are very dangerous.

1 h.p. = 550 ft. lb. per sec.

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$$

Chapter 39

HEAT AND LIGHT FROM ELECTRICITY

Electricity serves innumerable purposes in our everyday lives, but probably the most essential service it renders to all of us is in producing light where there is no natural light. When we push a switch, an electric current instantly flows through the wires in the bulb, and we have light. If we examine an electric light bulb, we notice a fine tungsten wire, or *filament,* through which the current flows. When we place a hand near the bulb, we realize that heat as well as light is given off. As the current flows, the filament becomes white-hot, or *incandescent*. It is this incandescent filament that lights our houses, schools, factories, and city streets.

What causes the heat in the filament, or rather, how is electric energy converted into heat in the filament? The wire that carries the current to the bulb hardly feels warm. How is the filament in the lamp different from the wire that conducts the current through the house? The difference is found in the *resistance* of the two wires.

Resistance and Heat. *The greater the resistance offered by a wire, the less is the current through it.* In trying to overcome resistance, electrical energy is changed into heat.

Substances vary in resistance. Those having a high resistance give off much more heat when a current passes through them than do those with a low resistance. You already know that copper is a good conductor of heat and electricity. Copper wire offers little resistance to a current and does not become appreciably hot when a current flows through it. It is therefore used in wiring systems and on long transmission lines. Nichrome, an alloy of nickel and chromium, has a high resistance. Therefore when a current flows through a nichrome wire, the wire becomes red-hot. The following experiment illustrates the difference in resistance between copper and nichrome.

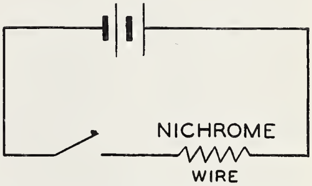


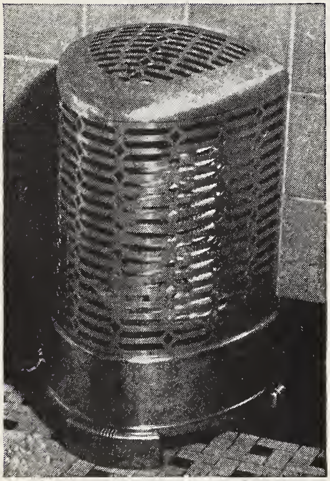
Fig. 39–1. A current flowing through nichrome wire produces heat.

Demonstration 39–1. The Heating Effect of an Electric Current.

Connect a piece of fine nichrome wire about four inches long to two dry cells and a switch as shown in the diagram. Use copper wire of the same cross-section to complete the circuit, and then close the switch. The nichrome wire becomes so hot that it glows; the copper does not.

Because of its high resistance nichrome wire is used in electric toasters and irons. The heating unit of an electric iron consists of a number of coils of nichrome wire wound on a mica frame or some other suitable support. What special properties are required of the substance on which the wire is wound?

Electric Heating. Electric heaters, being essentially only coils of nichrome wire, are simple electrical appliances. They are widely used. In localities where electricity is cheap, houses are sometimes heated by electricity. Even in areas where electricity is more expensive than coal, oil, or gas, electric heaters are often used because of their convenience. They do not produce smoke, soot, or objectionable gases. They do not have to be carefully adjusted, and they are safer than gas or oil heaters.



Courtesy *Westinghouse Corp.*

Fig. 39–2. An electric heater.

Heat produced by electric heaters usually costs more per B.T.U. than heat obtained from burning coal. This is due to the fact that in the electric power plant considerably less energy in the form of mechanical work is obtained from the turbine than is supplied in the form of heat from the burning coal. In other words, when coal is converted into electricity, heat energy is wasted and we pay for this wasted energy when we use electric heaters.

Electricity is a source of heat for many purposes besides heating rooms. Electric heaters are used extensively for heating water. Electric stoves, ranging from hot plates to large stoves with ovens, are coming into more and more common use because they are so convenient to operate. The flying suits sometimes worn by pilots flying at high altitudes are heated electrically.

Courtesy Westinghouse Corp.

Fig. 39–3. An electric stove.

In industry electric heating has many applications. In *electric welding*, for example, a large current is made to flow through the parts of the steel or other metal that are to be welded. The heat produced at the point of contact of the parts is so great that the metal pieces melt and run together, forming a strong bond when cool. In many cases electric welding is replacing the older method of joining pieces of metal by means of rivets.

The *electric furnace* produces the high temperatures needed to melt some metals and to carry out certain industrial processes, such as the manufacture of graphite from coke, for example. No nichrome wire is used. Usually the current passes directly through the material to be melted. The resistance of the material is sufficient to produce the high temperature required.

Fuses. If the insulation comes off the wires in an electric cord and if the wires then touch each other, a *short circuit* is formed. Such a circuit has very little resistance; it will allow so heavy a current to flow that the wires may become hot enough to start a fire in the walls of the building. To prevent such an occurrence, fuses are used in all electric circuits.

A *fuse* is usually a short strip of metal alloy with a low melting point. This strip is mounted in a holder and screwed or plugged into a socket so that it is in series with the electric circuit in the building. If too large a current flows through the house wiring, it melts the fuse, thereby breaking the circuit and turning off the electricity. Before a new fuse is inserted, the cause of the short circuit must be found. Unless the defect is corrected before the fuse is replaced, the new fuse will also burn out as soon as the current is switched on. Fuses used in ordinary house circuits are usually rated to carry 15 amperes and should not be replaced with fuses rated for more than this amount of current.

Safety Measures. Care should be taken at all times when handling electrical apparatus to prevent accidents. The voltage in most buildings is 110 volts. Under some circumstances this may give a dangerous shock. If, for example, one grasps a defective fixture while standing in water, a large enough current may flow through the body to cause death. Electric fixtures should therefore not be placed within reach of a bathtub.

Under no circumstances should a burned-out fuse be replaced with anything but a standard fuse of the correct rating. The wrong fuse may not be able to prevent large currents from heating the house wiring to the point where a fire results.

There is always possible danger in electric circuits. Therefore, if a circuit needs repairing, the work should be done by an electrician, never by an inexperienced person.

Courtesy National Safety Council, Inc.

Fig. 39–4. Light fixtures should not be located near plumbing fixtures. If the switch were defective and the cord were a metal chain, the woman in this picture might receive a serious shock.

Incandescent Lamp Filaments. The filament of an ordinary electric-light bulb is made of the metal tungsten. In order to give off as much light as possible, the filament in a lamp must be made *white*-hot. This requires an exceedingly high temperature, about 2000° C. Nichrome is not used for filaments because it melts well below this temperature. Tungsten, however, has the highest melting point of all metals (3370° C.). At 2000° C. it does not even vaporize to any marked extent.

But tungsten is a good conductor. How, then, can we make a tungsten wire with a high resistance? The resistance of a wire increases as the length of the wire increases; it also increases as the diameter of the wire becomes smaller. The tungsten filament must therefore be both long and thin. If you remove the filament from a burned-out light bulb and examine it under a magnifying glass, you will see how long and thin it is.

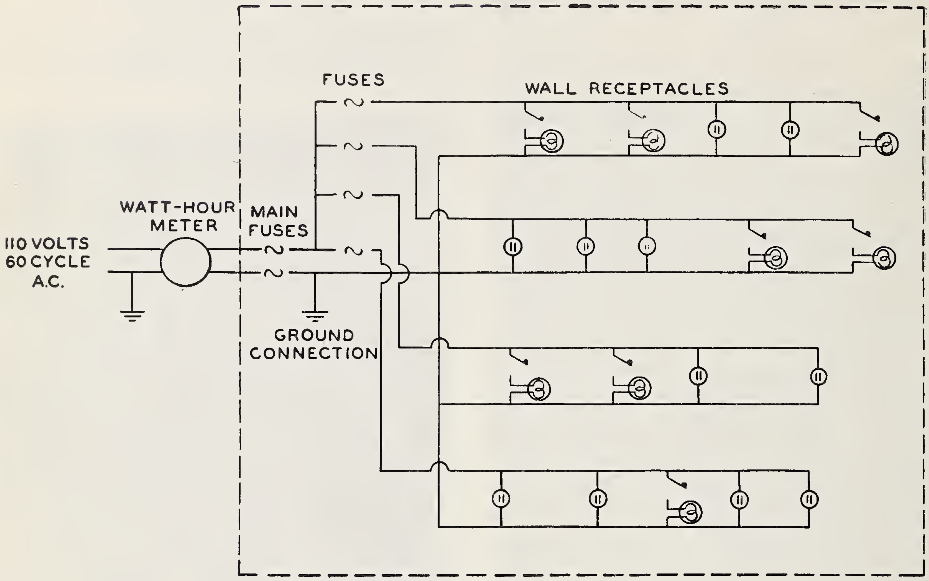


Fig. 39–5. A simple house-wiring circuit.

House Lighting Systems. Since many lights and electric appliances are used in houses and other buildings, let us see how they are connected to their source of power. All the lights and other devices in the house are connected in parallel. Fig. 39–5 shows four separate house-wiring circuits leading from the watt-hour meter, each with its own fuse. If all the lights and appliances were on one circuit and if all of them were in use at the same time, the wires might become overloaded with too much current. Another advantage of having several circuits is that if a fuse in one circuit burns out, lights on the other circuits can still be turned on. If all electric appliances were connected in series, the circuit would look like that shown in Fig. 36–14. Such a circuit would be impractical; for, if one light were turned off, all the lights and appliances in the building would go off at the same time because there would no longer be a closed circuit through the remaining lamps.

The watt-hour meter measures the total amount of electric energy used in all the circuits. It is frequently mounted on the outside wall of a house where it can be conveniently read. From the reading of the meter the cost of the electric energy supplied to the consumer is calculated.

THINGS TO REMEMBER

Heat is produced when an electric current flows through a resistance.

Nichrome wire is used in electric heating elements because it has a high resistance.

Electric heat is *cleaner, safer,* and *more convenient to control* than heat produced directly by combustion.

An electric *fuse* is an alloy with a low melting point that melts when an excessive current flows through it, and thus breaks the electric circuit.

An *incandescent* bulb contains a *tungsten* filament because tungsten has a very high melting point.

House lights and *appliances* are wired in *parallel,* and each circuit is protected by a fuse.

QUESTIONS

A

1. What kind of wire is used in electric heaters? Why is this kind of wire used?

2. Name two advantages of electric heating over coal heating.

3. What is the purpose of an electric fuse?

4. Describe the construction of the filament in an incandescent bulb.

5. Why are electric lights and appliances connected in parallel?

6. Determine which of the following statements are true and which are false. Then correctly reword the false ones.

- (*a*) Heat is produced whenever an electric current flows through a resistance.
- (*b*) An ordinary light bulb used in a house consumes about 10 kilowatts of power.
- (*c*) It costs ~~less~~ more to produce heat from electricity than to get heat by burning coal.
- (*d*) Ordinary house voltage is about 110 10 volts.
- (*e*) Ordinary house voltage can cause serious shocks.

7. What must happen to produce heat in an electric circuit? current must pass thro [illegible]

8. How is a fuse connected in an electric circuit? in series to control [illegible]

9. What is a short circuit? [illegible]

B

10. Describe what happens when a fuse burns out.

11. Why is a fuse not connected in parallel with a circuit?

12. What should be done before replacing a burned-out fuse?

13. Why is heat produced from electricity more expensive than heat produced directly from burning coal?

PROJECT

Reading a Watt-Hour Meter. Read and record the watt-hour meter for your house. Read the meter again a week later. Calculate how much electricity was used during the week. From the cost of electricity in your town calculate your electricity bill for the week.

A watt-hour meter dial is shown in the figure. The right-hand dial registers kilowatt-hours from 0 to 10. The next dial registers them in units of tens, the third in units of hundreds, and the fourth in units of thousands. Reading from left to right, the dials in the figure show a total reading of 9121 kilowatt-hours.

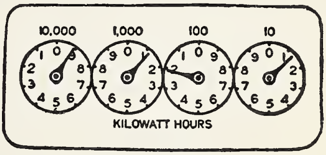


Fig. 39–6. A watt-hour meter.

REVIEW QUESTIONS ON UNIT 7

A

1. Complete each of the following statements by supplying the correct word or phrase.

- (*a*) An electric generator converts —?— into electric energy.
- (*b*) An electric motor converts electric energy into —?—.
- (*c*) More than 60 percent of the electricity produced in the United States comes from —?—. coa
- (*d*) Hydroelectric power is electric power produced by —?—.

2. How may heat energy be obtained from electrical energy?

3. What is a kilowatt?

4. How would you make an electromagnet?

5. How is electricity often produced in mountainous countries?

6. What is a Diesel-electric locomotive?

7. What happens when a body becomes charged: (*a*) positively; (*b*) negatively by friction?

8. Compare the electrical properties and uses of copper wire and nichrome wire.

9. Why are household electrical appliances connected in parallel?

10. Why are fuses used, and how are they connected in a house-wiring system?

11. What precautions must be observed when electricity is used in the home?

B

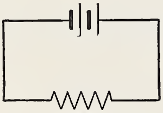
12. Tell how to generate an electric current in a coil of wire by means of a magnet.

13. Determine which of the following statements are true and which are false. Then correctly reword the false ones.

- (*a*) Positive charges attract each other.
- (*b*) North magnetic poles do not attract each other.
- (*c*) A positive electric charge attracts a negative electric charge.
- (*d*) An electric current is measured in amperes.
- (*e*) Electric power is measured in volts.
- (*f*) The earth has a south magnetic pole in the Arctic.

14. Explain just what you should do when a fuse blows out in your home.

15. Each cell gives 1.5 volts. Find (*a*) the current flowing through the resistor and (*b*) the power given off in the form of heat in the resistor.



16. How much would it cost to run a 50-ohm lamp from a 110-volt power supply for 24 hours if electrical energy costs 4 cents per kilowatt-hour?

17. What is the efficiency of a $\frac{1}{4}$-horsepower motor that draws 2.5 amperes from a 110-volt supply?

18. When you comb your hair in dry weather, the comb becomes negatively charged and your hair stands on end. Explain what has happened.

19. (*a*) Draw a diagram of a circuit to include two dry cells, a switch, a light bulb, a resistor, an ammeter, and a voltmeter across the lamp.

(*b*) If the voltage drop across the lamp is 1.5 volts and the ammeter reads 3 amperes, find the resistance of the light bulb. R = .5

20. (*a*) Christmas tree lamps are often connected in series, with eight lamps in a string. If the string operates on 112 volts, what is the voltage across each lamp? 14 volts. $\frac{112}{8}$

(*b*) If the total current used by the string is $\frac{1}{2}$ ampere, what is the resistance of each lamp? 28

21. If electricity costs 5 cents per kilowatt-hour, how much would it cost to burn a string of eight 2-watt lamps for 100 hours?

22. Describe carefully three different ways in which electricity can be made to move from one body to another. Tell what makes the electricity move in each case.
friction

23. Draw a diagram of an AC generator and explain how it works.

24. Draw a diagram of a DC generator and explain how it works.

SUGGESTIONS FOR FURTHER READING

A

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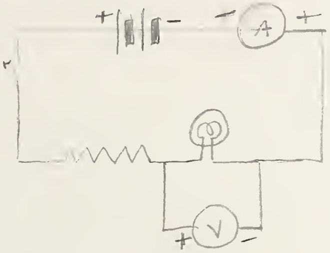
Cindy



$2 = 1.5$

$I = \frac{E}{R}$

$R = \frac{E}{I} = \frac{1.5}{2}$

$I =$

$\frac{1}{2} = \frac{14}{5}$

$R = \frac{14}{\frac{1}{2}}$

$= 2\ 8$ ohms

Voltage

electricity

Unit 8

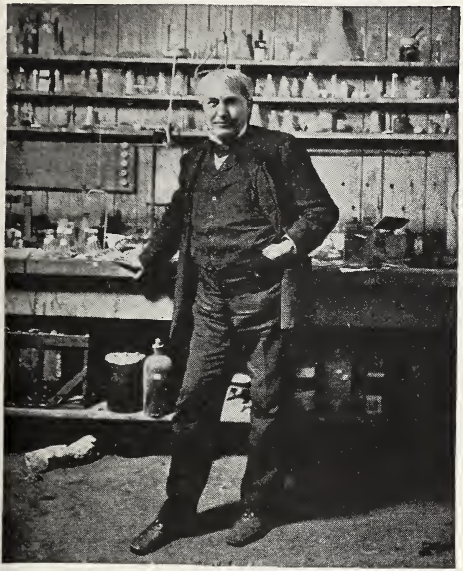
LIGHT

40. ARTIFICIAL LIGHT
41. LIGHT AND ITS EFFECTS
42. OPTICAL INSTRUMENTS
43. WHAT IS COLOR?

Chapter 40

ARTIFICIAL LIGHT

The electric lamp which we discussed in Chapter 39 is a relatively recent discovery. It was invented by Thomas Edison in 1879.



Courtesy Thomas A. Edison, Inc.

Fig. 40–1. Thomas Edison in his laboratory, about 1906. He had invented the filament-type electric lamp twenty-seven years earlier.

The story of the development of light is remarkably similar to the story of the development of power. Early sources of artificial light were crude and inefficient, but they slowly improved as man came to understand the laws of nature. Light has always been obtained as a result of producing heat, and the heat was usually obtained through the combustion of a fuel. The heat evolved in producing light is thus a wasteful by-product. When scientists solve the problem of producing light without heat, there will be a great saving of fuel.

There is one outstanding difference between the development of light and the development of power. From early times man has harnessed winds and running water to do work for him. Light, however, has come to him from the sun as a gift. But the sun gives light for only part of the day. In early times, therefore, nearly all human activity began with the rising of the sun and ended with its setting. As civilization progressed, man invented means of producing light which could be used during the hours when there was no sunlight. What were the sources of light before man learned to generate electricity?

Sources of Light. For centuries the only portable lights were burning sticks. Pine pitch was often placed on the end of the stick because it made the flame brighter, and it lasted longer. Many of the old castles in Europe used pine torches as late as the 15th century.

The Greeks and Romans used *oil lamps*. These were shallow dishes holding oil which was probably extracted from olives. The small, wavering flame in such lamps gave little light, and it was accompanied by an unpleasant odor.

Another source of light was the *candle.* Candles were used long before kerosene was known. In England they were made from tallow, or sheep fat. They were used to give light in coal mines before the Davy lamp was invented. In New England the early settlers used the wax from the bayberry, which grows abundantly in that region.

Lighting was often one of the great lacks in early pioneer life. You will recall that Abraham Lincoln had to study by the light of the fire in the fireplace because he had no candles or lamps. Today candles are used chiefly for decorative and religious purposes.

Coal gas, you may recall, was first used as fuel for lighting about 1820. A special burner was used, yet coal gas gave a sooty, yellowish flame.

About 1850 the *kerosene lamp* was invented. Kerosene lamps required a supply of petroleum. When Drake struck oil in Pennsylvania in 1859, he was interested in getting oil for kerosene lamps, not for internal-combustion engines, which had not yet been developed.

Courtesy Consolidated Edison Co. of New York, Inc.

Fig. 40–2. Man's activity is no longer limited to daylight hours. New York City at night is ablaze with artificial light.

THE DEVELOPMENT OF ELECTRIC LIGHTING

The next improvement in artificial lighting was the first electric lamp. Before this invention, as we have seen, all light had been produced by burning a fuel. In electric lighting, however, an object is made hot enough to give off light without burning. The first successful *carbon arc* was invented by Sir Humphry Davy in 1825. The light produced by a carbon arc is so bright that the eyes must be protected from it by dark glasses.

Demonstration 40–1. Making a Carbon Arc.

Obtain two sticks of carbon and on coarse sandpaper grind the ends to a point. Mount the rods on separate ringstands. (*Caution:* Do not touch both ringstands at the same time, as the difference in voltage between them can give you a bad shock.) Connect the rods with wires to an electric iron or to a bathroom heater, which serves as a resistor to limit the amount of electricity passed by the arc. The arrangement is shown in Fig. 40–3. Connect the whole apparatus to an electric outlet and then, by moving *one* of the stands, touch the two carbons together. They should become red-hot at the point of contact; they can then be separated slightly to form a bright carbon arc.

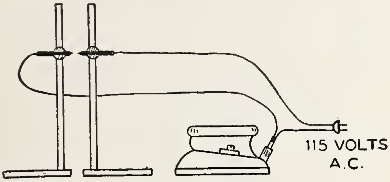
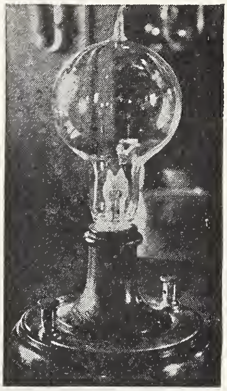


Fig. 40–3. A simple carbon arc can be made from two old battery carbons mounted on stands and connected as shown. *Caution:* Always use dark-colored glass when looking at the light.

The light is produced by incandescent (white-hot) particles of carbon streaming across the gap between the electrodes. The arc can be blown out by a good puff of air.

Carbon arcs were used for many years in street lighting. They were used to light the streets of Baltimore as early as 1845. The great disadvantage of the carbon arc is that it has to be continually adjusted as the carbons evaporate.

A Carbon Filament. The carbon arc was not well suited for home use. Thomas Edison believed that a long thin thread, or *filament,* of carbon should be used. He spent many years trying to find a suitable carbon filament, and in 1879 he finally made one out of bamboo fiber. The fiber was partly oxidized in a hot oven to turn it into carbon; then, to prevent it from burning away, it was mounted in a glass bulb from which the air was removed. The *carbon-filament lamp,* as it was called, proved successful and was widely used. Its chief drawback was that the filament was very fragile. An early model of an Edison lamp is shown in Fig. 40–4.



Courtesy Thomas A. Edison, Inc.

Fig. 40–4. A replica of the original filament lamp made by Edison in 1879.

A Metal Filament. Today tungsten has replaced the carbon as a filament. Tungsten is a brittle metal. Because at first tungsten could not be drawn into a wire, it took years to perfect the tungsten filament. Hot tungsten powder is hammered into a small rod, which is then forced through a series of smaller and smaller holes, or dies, until it has the required fineness. For some lamps the wire must be drawn so fine that a single pound of tungsten is drawn into forty miles of wire.

Dr. Irving Langmuir made several improvements in the tungsten lamp. First, he found that tungsten filaments would last longer if, instead of being evacuated, the lamp were filled with nitrogen gas. In a vacuum the evaporation from the hot filament caused a black deposit of tungsten to form on the inside of the bulb. The pressure of the nitrogen reduced the evaporation and thus lengthened the usefulness of the bulb. Langmuir also discovered that the heavier the wire the longer it lasts. But a heavy wire has too low a resistance. Langmuir therefore coiled fine tungsten wires into a thick coil and then coiled this again into a still thicker pencil of wire, as shown in Fig. 40–5. Even at a high temperature a filament made with this coiled wire does not evaporate as rapidly as the wire in the older lamps. And the higher the temperature the whiter and brighter is the light produced. Thus more illumination is produced at a lower cost. In 1879 light from electricity cost about thirty times as much as it does today.

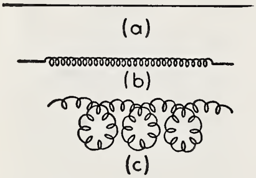


Fig. 40–5. Thin tungsten wire (*a*) is twisted into a fine coil (*b*), and this is twisted again into a heavy filament (c) for use in lamp bulbs.

Demonstration 40–2. Examination of an Incandescent Lamp.

Obtain a 100-watt clear-glass bulb of modern make. Examine the construction of the lamp, especially the filament and its supports, as shown in Fig. 40–6. Can you find the exhaust tube through which air was pumped out?

Hold the bulb in a heavy towel and with a sharp file make a scratch about an inch long around the glass near the base. Screw the lamp into a socket and turn on the electricity. When the lamp is hot, drop a little water on the crack. The glass should crack all the way around without disturbing the filament, which continues to glow. After several seconds a white cloud of tungsten oxide begins to form inside the bulb as the nitrogen is slowly replaced by air. Finally, turn off the electricity, remove the glass, and examine the filament under a magnifying glass. Careful examination shows that the filament is really a coiled coil of fine tungsten wire. Break open the metal base of the lamp to find where the filament is connected to the metal base.

Vapor Lamps. The newest sources of light are vapor lamps, in which electricity passes through a gas. Glowing gases produce much less heat than ordinary filament lamps. How does a gas produce light? And are all gases suitable for this purpose?

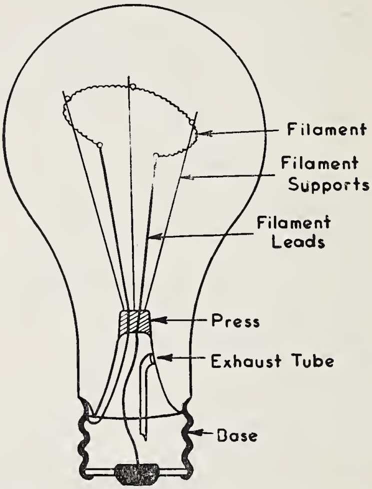


Fig. 40–6. A gas-filled tungsten lamp with a coiled filament.

According to one theory, light is produced in a substance when the electrons in its atoms are disturbed. When atoms are packed close together, as in a solid or liquid, the easiest way to disturb electrons is by applying heat. When atoms are in a vapor form, however, the electrons are best disturbed by other fast-moving electrons, as in a flow of electricity.

The real problem is to find vapors which are suitable for ordinary illumination. Neon gas produces only a reddish color that is not very bright. It is used, however, for advertising signs and for decorative purposes. Sodium vapor, obtained by heating sodium metal in a sealed bulb, produces a strong yellow light, and lamps containing sodium vapor are sometimes used in highway lighting. But the yellow color makes them unsuitable for general use.

Demonstration 40–3. Light from Gases.

Wrap a piece of asbestos around the top of a Bunsen burner as in Fig. 40–7, and tie it in place. Then slip it off carefully and soak it in a strong solution of table salt. Wipe off any excess solution, replace the asbestos on the burner, and light the gas. After a moment a bright yellow flame is produced. Turn out all white lights and examine your hands and your classmates' faces in the yellow light. Can you explain the results?

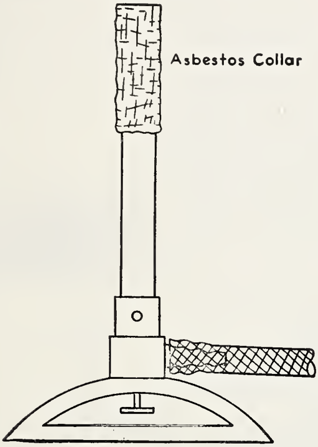


Fig. 40–7. Colored flames can be produced by soaking asbestos collars in chemicals and then heating them at the top of a Bunsen burner.

Soak other pieces of asbestos in strontium chloride or lithium chloride. What colors are produced when these are heated? Is the color characteristic of the chloride or of the metal? If a spectroscope is available, examine the light to tell just which colors are produced by each substance.

Mercury vapor gives a greenish light that changes the color of ordinary objects. Such lights, however, are often used in factories where careful machine work is being done, since the color enables even poor eyes to see better.

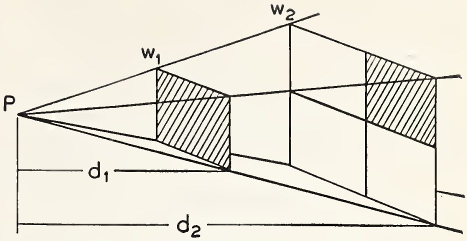
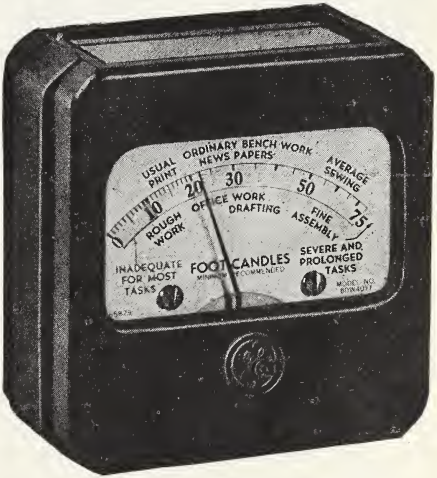


Fig. 40–8. Illumination falling on a surface decreases as the distance from the source increases. The light P passing through area W_1 is spread over all of W_2, which is the same size as W_1 but twice as far from P. The illuminated areas are the same size but W_2 is only one-fourth as brightly lighted as W_1.

Fluorescent Lamps. Recently scientists have found a way to make mercury lamps produce white light. The inside of the glass tube that will hold the mercury vapor is coated with



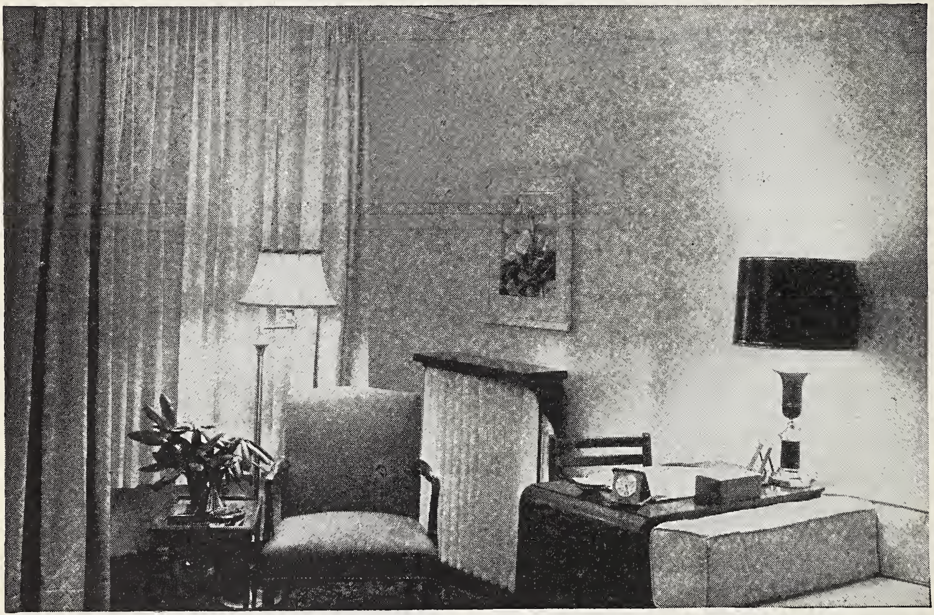
Courtesy General Electric Co.

Fig. 40–9. The illumination falling on a surface is measured in foot-candles by a light-meter.

chemicals, such as zinc sulfide, that glow with a nearly white light when they absorb the light of mercury vapor. In other words, some of the light waves given off by the mercury vapor strike the molecules of the substance on the glass and cause them to emit white light. This process is called *fluorescence.* Very little heat is produced in this process. In other words, a high proportion of the electric energy is converted into light and relatively little is wasted as heat. As a result, a fluorescent lamp is four times as efficient as a good incandescent lamp.

Thus far scientists have not discovered a satisfactory way of getting light without some heat. Light and heat appear to be inseparable; whenever we find one we find the other. Even the sun, which is our chief source of light, is also our main source of heat.

Illumination. The proper adjustment of artificial light for human needs is important. The eyes may be damaged by reading in a poor light; that is, by reading a page that is illuminated either by too little or by too much light. Illumination is measured in *foot-candles,* a measurement based on the amount of light produced by the standard candle. *One foot-candle is the illumination of a surface that is one foot from a one-candle-power source.* A 16-candle-power source produces 16 foot-candles of illumination at a distance of 1 foot; but at a distance of 2 feet the illumination is only 4 foot-candles, and at 4 feet only 1 foot-candle. In other words, a stronger lamp provides more illumination than a weaker one, but the illumination decreases rapidly as the distance from the lamp increases. This is demonstrated by the diagram in Fig. 40–8, in



Courtesy General Electric Co.

Fig. 40–10. Proper lighting in the home.

which light leaving the source point P and going toward the window W_1, continues toward window W_2 in diverging rays. If W_2 is twice as far from P as W_1, the light will cover four times the area at W_2 and will be only one-fourth as bright.

Most authorities agree that for studying and reading small type the illumination on a page should be from 30 to 50 foot-candles. This light can be provided by a 60-watt lamp about eighteen inches away from the work. For sewing on dark materials, for fine needlework, and for precision shopwork, the illumination should be as much as 100 foot-candles. A *foot-candle meter*, shown in Fig. 40–9, is used for measuring illumination.

Light must also be properly distributed. A bright light poorly placed causes *glare*, which obscures the work and tires the eyes. A room should have enough general illumination so that the regions of brightest light do not stand out sharply against the background. This condition has been well met in the room shown in Fig. 40–10.

In spite of the advances in artificial lighting, daylight is still the best and most readily available light source. In open sunlight the illumination is usually from 500 to 1,000 foot-candles, and excellent interior illumination may be obtained in any room provided with good windows and exposure to the sky.

THINGS TO REMEMBER

Kerosene lamps were invented about 1850.

Edison invented the *carbon-filament* lamp in 1879.

Vapor lamps produce light by passing electricity through a gas.

In *fluorescent lamps* the light of mercury vapor makes chemicals glow with a bright white light.

One *foot-candle* is the illumination of a surface one foot from a one-candle-power source.

Satisfactory *reading illumination* for fine print is from 30 to 50 foot-candles.

QUESTIONS

A

1. From what kinds of materials are candles made?

2. What are the chief disadvantages of kerosene lamps?

3. Describe the development of electric filament lamps?

4. Why is nitrogen gas often used in modern filament lamps?

5. Modern fluorescent lamps contain what gas?

6. Define the term *foot-candle.*

7. How does the light output of a sodium lamp compare with that of an incandescent filament lamp using the same amount of electric power?

8. State two advantages of the tungsten-filament electric lamp over Edison's carbon-filament lamp.

B

9. Compare the terms *candle power* and *foot-candle.*

10. Describe a carbon arc and explain how it operates.

11. Describe the operation of a vapor lamp.

12. How does a fluorescent lamp differ from a neon lamp in its production of light?

13. State one reason why a fluorescent lamp is more efficient than a lamp with a hot filament.

PROJECT

Measuring Illumination. The illumination in your classroom should be measured with a foot-candle meter like the one shown in Fig. 40–9. If your school does not have one, ask the electric light company if you may borrow one. These instruments are very delicate and must not be jarred or dropped.

Place the meter face up on a desk. Be sure you are not blocking the light. Record the meter reading with the curtains up, and then with the curtains down and the lights on, if possible on both sunny and cloudy days. Is the illumination satisfactory for general reading under all conditions?

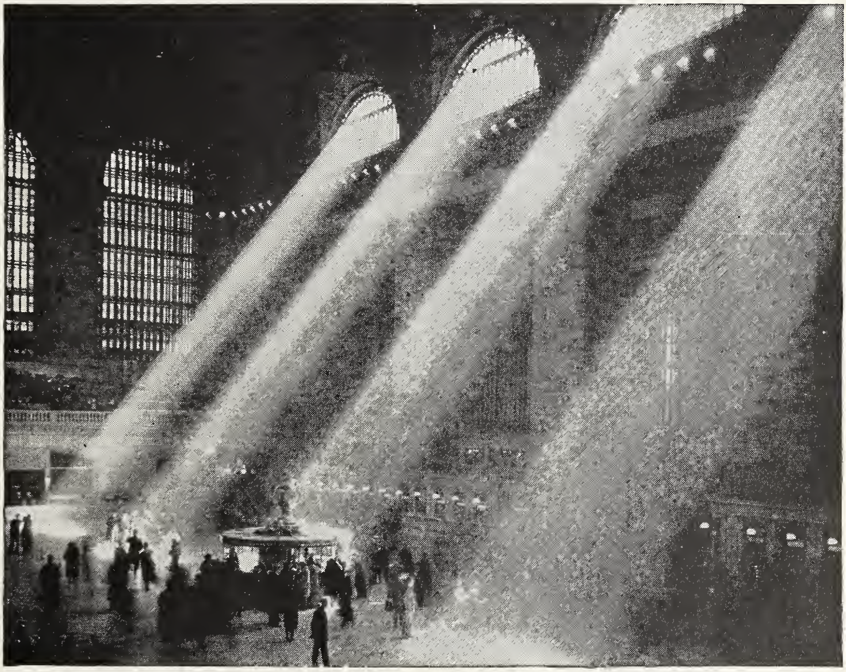
Repeat the above experiment on desks near the window, in the far corners of the room, and at the blackboard. Is the room well lighted? How might it be improved? Write a report on your experiment.

Chapter 41

LIGHT AND ITS EFFECTS

Light and heat are closely related; in fact, heat radiation is really a form of invisible light. Light and radiant heat both travel through a vacuum; otherwise the light and heat from the sun would not reach us. Both light and radiant heat travel at the tremendous speed of 186,000 miles a second. At this speed it would take light only one-seventh of a second to travel around the earth.

An irregular-shaped piece of cardboard held in the sunlight will cast a shadow that has the same shape as the cardboard. This can be explained only by the fact that the light from the sun travels in straight lines. *Light, and in*



Courtesy New York Central System

Fig. 41–1. The sun's rays coming through the windows of the Grand Central Terminal in New York City show that light travels in straight lines.

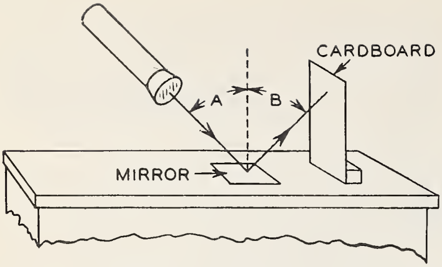


Fig. 41–2. Reflection of light from a mirror. The angle of reflection, *B*, equals the angle of incidence, *A*.

fact all radiation, travels in straight lines. If on a sunny day you observe carefully the shapes and sizes of the shadows cast by buildings, clouds, telegraph poles, and other objects, you will see that they can be explained only by the fact that light travels in straight lines.

Reflection of Light. When light strikes a flat surface its direction is changed. This change is known as *reflection,* which means that the light is bent back from the surface. The following demonstration shows how light is reflected from a smooth surface.

Demonstration 41–1. To Reflect Light from a Mirror.

Place a small mirror flat on a table in a darkened room. Direct the beam from a flashlight toward the mirror as shown in Fig. 41–2, and hold a large piece of white cardboard in the reflected beam. A little smoke from a glowing splint in the air above the table will help to make the light visible. To sharpen the beam, the face of the flashlight should be covered by a piece of black cardboard that has a hole about a quarter of an inch in diameter placed between the center and the edge of the lens.

Follow the path of the light from the flashlight to the white cardboard, and with a protractor measure the angles A and B shown in the figure. These are the angles between the beam of light and the perpendicular. Angle A, the angle at which the light strikes the mirror, is called the *angle of incidence;* angle B, the angle at which the light is reflected from the mirror, is called the *angle of reflection.* How do these angles compare? Change angle A by moving the flashlight and move the white cardboard until it is again in the path of reflected light. Again measure and compare angles A and B.

You will find that the angle at which a light beam is reflected from a mirror is always equal to the angle at which it strikes the mirror. In other words, *when light is reflected from a smooth surface, the angle of reflection equals the angle of incidence.*

When light is reflected from a surface that is not perfectly smooth, it is scattered in all directions. This is called *diffuse reflection,* and light reflected in this way is called *diffuse light.*

Objects that reflect only a small amount of the light that falls on them and allow most of it to pass through them are said to be *transparent.* Glass, water, and many plastics, for example, are transparent. Objects that permit no light to pass through are *opaque.* There are countless opaque objects all around us. Other materials let some light pass through

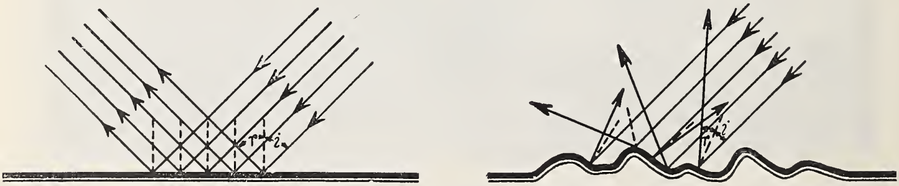


Fig. 41–3. The diagram at the left shows regular reflection; the one at the right, diffuse reflection.

them but scatter most of the light that strikes them. Such materials are said to be *translucent*. The glass on most light bulbs, for example, is translucent in order to produce soft shadows.

Images in a Plane Mirror. When we want to see an image of ourselves, we look in a mirror. How and where is this image formed? The position of the image in a plane mirror can be found by the following method.

Demonstration 41-2. An Image in a Plane Mirror.

Draw a long straight line in the middle of a large piece of paper. Then place the paper over a sheet of thick cardboard on a table and support a small mirror vertically so that its *back* edge lies along the line. Next stick a large pin vertically into the paper about four inches from the front surface of the mirror as shown in Fig. 41-4. Now, with one eye closed, locate the image of the pin by looking into the mirror along the table. Then stick two small pins into the paper along the line of sight of the image and as far apart as possible, as shown in Fig. 41-4. These pins must be *exactly* lined up with the image of the large pin. The image of the large pin lies along this line. Now repeat the process sighting along a different direction. The image of the large pin also lies along this line. Remove the pins and the mirror and, with a ruler draw a diagram like that in Fig. 41-5, using the pinholes in the paper to determine the lines.

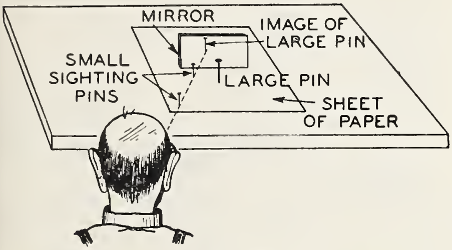


Fig. 41-4. Sighting the image of a large pin in a plane mirror.

Since the light from the large pin is reflected from the mirror according to the law of reflection, angle A equals angle B, and angle C equals angle D. Extend the lines of the two reflected rays behind the mirror. They intersect at a point O′. This means that to the eye the two reflected rays *appear* to be coming from this point, since we always judge the position of an object by assuming that the light has traveled *in a straight path* from the object to the eye. Point O′ is therefore the position of the image, and the pin *appears* to be at this point. Careful measurements on the diagram show that *this image of the pin is as far behind the mirror surface as the pin is in front of it.*

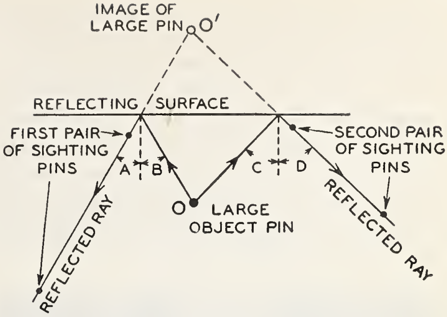


Fig. 41-5. Locating the image of a large pin in a plane mirror.

Curved Reflectors. The fact that the direction of light rays can be changed by reflection has been used to make many useful optical devices. For example, Fig. 41-6 shows how a concave reflecting surface can be used to ob-

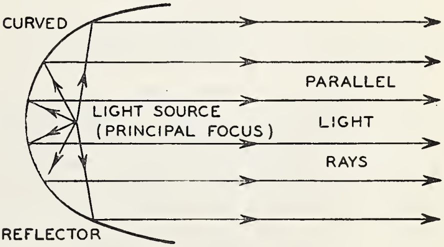
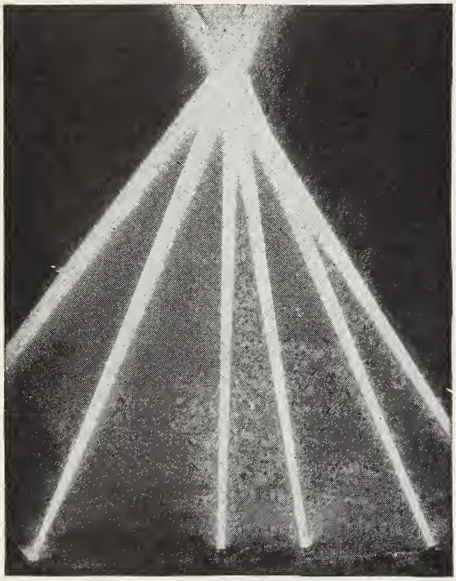


Fig. 41-6. A curved reflector focuses light into a narrow beam of parallel rays from a source placed at the principal focus.

tain a powerful beam of light. The rays of light from the source go out in all directions but some of them are concentrated into a narrow beam of parallel rays by reflection from the curved surface. This is because the light source is placed at the so-called *principal focus* of the reflector. Curved mirrors of this type are used in searchlights, flashlights, and automobile headlights for concentrating light into a narrow beam.



Courtesy U.S. Army

Fig. 41–7. Searchlights such as these have concave reflecting surfaces.

Demonstration 41–3. To Concentrate Light with a Concave Mirror.

Mount a large concave mirror so that it is directly facing the sun. Hold a small piece of paper in front of the mirror and move it back and forth until a bright spot on the paper shows where the parallel rays from the sun are concentrated. This point is the *principal focus.* The distance between the center of the mirror and the principal focus is called the *focal length.*

A concave mirror can also be used to form images of objects placed in front of it. In the reflecting telescope on Mount Palomar a concave mirror 200 inches in diameter forms images of the heavenly bodies. Let us now use a concave mirror to see how images are formed.

Demonstration 41–4. To Produce a Real Image with a Concave Mirror.

In a darkened room place a lighted candle and a concave mirror about 6 feet apart on a table. Hold a piece of tissue paper in front of the mirror. Move the paper back and forth until a clear image of the candle flame appears on the paper.

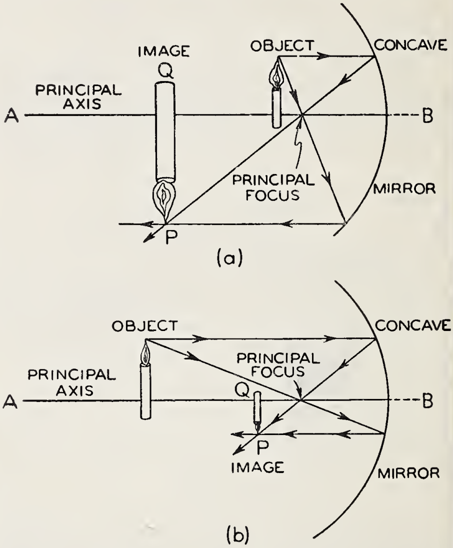


Fig. 41–8. Real images formed by a concave mirror. The image is magnified in (*a*) and diminished in (*b*). (Note: In this and other diagrams in this chapter, for reasons of clarity rays of light are shown as leaving only one point on the object. Actually, they leave all points.)

You will notice that the image of the flame is upside down; it may be either larger or smaller than the flame. This type of image is known as a *real* image.

Fig. 41–8 shows how both a larger and a smaller image are formed. The line *AB* through the center of the mirror is called the *principal axis* of the mirror. The light from the top of the flame that goes out parallel to the principal axis is reflected so as to cross it at the principal focus. A ray from the top of the flame that goes through the principal focus before striking the mirror will be reflected along a direction parallel to the principal axis. These two rays cross at *P*. Actually *all* the rays that diverge from the top of the flame and strike the mirror must converge at this point. Hence we have light rays diverging from this point just as though the top of the flame were located there. This point is therefore the position of the image. Similarly, all the rays from the base of the flame come to a focus at *Q*.

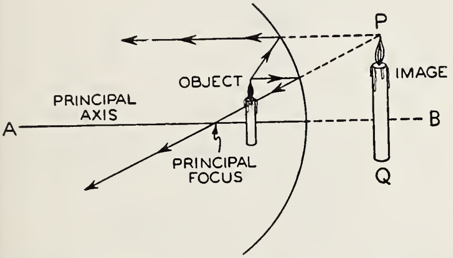


Fig. 41–9. A virtual image formed by a concave mirror.

The images shown in Fig. 41–8 are *real* images because the light actually comes to a focus and diverges from the point where we see the image. Another type of image is obtained from a concave mirror when the object is closer to the mirror than the principal focus.

Demonstration 41–5. To Produce a Virtual Image with a Concave Mirror.

Hold a lighted candle a few inches from a concave mirror. Look into the mirror at the image that is formed and you will notice that it is right side up and is magnified. The formation and position of such an image is shown by the ray diagram in Fig. 41–9.

Notice that the light does not *actually* diverge from the position of the image but only *appears* to diverge. This image is called a *virtual* image. Concave mirrors are used in this manner for shaving and for applying make-up because of the magnification of the virtual image.

Reflecting telescopes, such as that on Mount Palomar, use a concave reflector to produce an effect just the opposite of that of a headlight reflector. Here the parallel rays from an object, such as the moon or a planet, are concentrated by a curved reflector and then directed through an eyepiece so that the image appears larger than when the object is seen with the naked eye.

Courtesy Bausch and Lomb Optical Co.

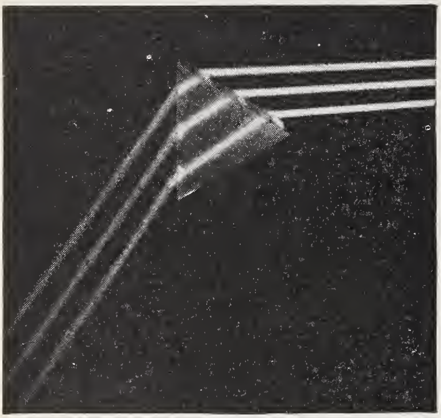
Fig. 41–10A. Refraction of light by water. This painting depicts Alhazen, famous 11th century Arabian scholar, studying this phenomenon, which led him to dispute the ancient theory that visual rays emanate from the eye.

Refraction of Light. If a stick is partly immersed in a pail of water, it appears to be bent at the point where it enters the water. This apparent bending is due to the fact that the light coming from the stick beneath the surface of the water is bent just as it leaves the water. The bending of light in this manner is called *refraction*. It can be shown in the following way.

Demonstration 41–6. The Refraction of Light.

Half fill a large round-bottom flask (1,000 cc.) with starch solution and in a darkened room direct the beam of a flashlight through the water as shown in Fig. 41–11. Find the emerging beam of light with a piece of white cardboard. A little smoke in the flask from a glowing splint will make the beam more visible in the air.

Imagine a line drawn perpendicular to the surface of the solution through the point at which the beam of light enters. You will then see that as the light goes from the air into the water it is actually bent *toward the perpendicular.* If the light were going from the water into the air it would follow the same path but in the reverse direction; that is, as it left the water it would be bent *away from the perpendicular.*



Courtesy General Motors Corp.
Fig. 41–10B. Refraction of light by a prism.

These facts can be summarized in the *Law of Refraction,* which states: *Whenever light goes from a less dense medium to a more dense medium, it is bent toward the perpendicular; conversely, whenever it goes from a more dense to a less dense medium, it is bent away from the perpendicular.*

The results of this experiment explain why a stick partly immersed in water appears bent. The light from the submerged part of it is bent away from the perpendicular upon emerging from the water. As a result, the light comes to our eye in such a direction that each of the submerged parts of the stick appears to be a little higher than it really is. This is shown by Fig. 41–12.

When the Indians shot fish underwater with bows and arrows they were confronted with this effect in aiming at their targets. For, unless they were shooting vertically downward into the water, they found by experience that to hit the fish they had to aim a little below where it appeared to be.

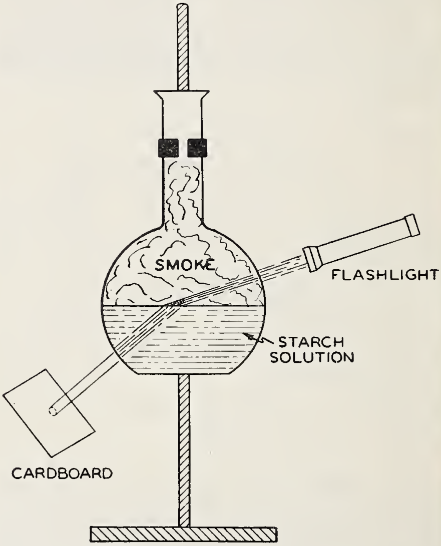


Fig. 41–11. Water bends a beam of light.

Another interesting demonstration of refraction can be performed with a small bowl, a coin, and some water.

Demonstration 41–7. Seeing Over the Edge of a Dish by Refraction.

Place a coin in the bottom of a shallow dish or bowl and sight over the edge of the bowl, lowering your head until the coin just disappears from view behind the edge of the dish. Without moving your head, slowly pour water into the dish. As the surface of the water rises the coin

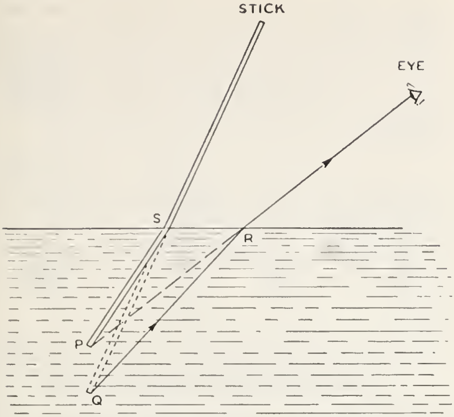


Fig. 41–12. A stick appears bent in water because light from point Q on the stick is bent as it leaves the water and the eye sees this point on the stick at *P* instead of at Q. All other parts of the stick that are submerged appear at different positions so that the image of the submerged stick appears along *PS*.

will come back into view. Fig. 41–13 shows the path of the light and the position of the image of the coin.

Lenses. A curved piece of glass, called a *lens*, is also used to bend light rays so that they can be put to practical use. Fig. 41–14 shows two types of lenses, convex and concave, that are used in optical instruments. A *convex* lens is thicker in the middle than at the edges. A *concave* lens is thicker at the edges than in the middle.

A convex lens can be used to concentrate both light and heat at a point called the principal focus. Indeed, before the invention of the Bunsen burner, the heat of the sun was concentrated in this way to provide heat for chemical reactions.

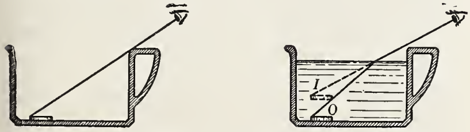


Fig. 41–13. Seeing over the edge of a dish by refraction.

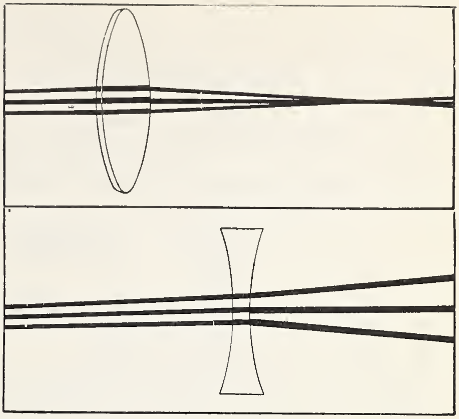


Fig. 41–14. Refraction of light by convex (top) and concave (bottom) lenses.

Demonstration 41–8. To Use a Convex Lens to Concentrate the Rays of the Sun.

Hold a large convex lens between a piece of white cardboard and the sun. Move the lens until a small bright spot appears on the cardboard. The bright spot is an image of the sun, and the sun's light is concentrated at the principal focus of the lens.

Fig. 41–15 shows the path of the sun's rays through the lens. Notice how the rays are bent as they pass through different parts of the lens. This type of bending may be used to produce pictures of images of objects on a screen, as shown by the following demonstration.

Demonstration 41–9. To Produce a Real Image with a Convex Lens.

In a darkened room arrange a large white cardboard screen and a candle flame on a table as

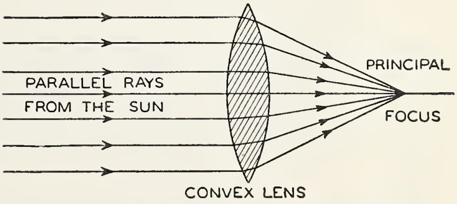


Fig. 41–15. The sun's rays are concentrated at the principal focus of a convex lens.

shown in Fig. 41–16. Now place a convex lens between the candle flame and the cardboard screen and move the lens back and forth until an image of the flame appears on the screen.

The diagram in Fig. 41–17 shows how the image is produced. All the light from the top of the flame that passes through the lens comes to a focus at point *P*, while all the light from the bottom of the flame comes to a focus at *Q*; and in the same way light from all the other parts of the flame come to a focus at the corresponding points between *P* and *Q*.

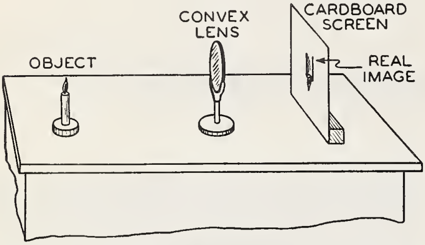


Fig. 41–16. A real image produced by a convex lens.

This image will be larger or smaller than the object, depending on the distance between the object and the lens. If this distance is greater than the focal length of the lens but less than twice the focal length of the lens, the image will be real, inverted, and magnified. If it is greater than twice the focal length, it will be real, inverted, and diminished.

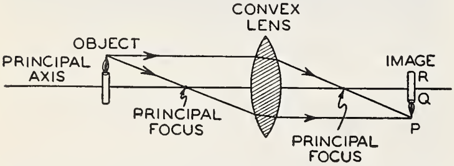


Fig. 41–17. Formation of a real image by a convex lens.

As in the case of a concave mirror, a virtual, erect, and enlarged image is formed if the object is placed closer to the lens than the principal focus. This is exactly what happens when a convex lens is held close to a printed page or a small object and used as a *magnifying glass.*

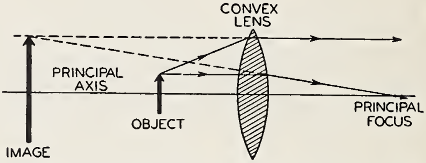


Fig. 41–18. An enlarged virtual image is formed by a convex lens used as a magnifying glass.

Demonstration 41–10. To Use a Convex Lens as a Magnifying Glass.

Using a convex lens as a magnifying glass, examine some small objects, such as the fibers in a piece of cloth, grains of salt, or a piece of wood. What can you see that you did not notice with your naked eye?

Fig. 41–18 shows how the image is formed when a convex lens forms a virtual image. How do you know from the diagram that the image is virtual?

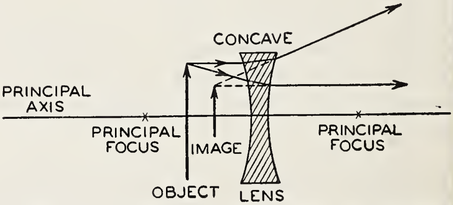


Fig. 41–19. Formation of an image in a concave lens.

Convex lenses, as we shall see in the next chapter, are used in many optical instruments such as telescopes, microscopes, and cameras.

A *concave* lens always produces an erect, virtual, and diminished image of the object regardless of the position of the object. Fig. 41–19 shows how and where an image is formed by such a lens. Concave lenses are used in eyeglasses to correct nearsightedness

THINGS TO REMEMBER

Light travels at *a speed of 186,000 miles per second.*

Light travels in *straight lines.*

When light is reflected from a smooth surface, the *angle of reflection* is equal to the *angle of incidence.*

The *image* in a plane mirror is always as far behind the mirror as the object is in front of it.

Light rays always are bent or refracted *toward* the perpendicular when they pass from a less dense to a more dense substance, and *away* from the perpendicular when they pass from a more dense to a less dense substance.

Concave mirrors are used to concentrate light and produce images.

A *lens* is a piece of glass with curved surfaces that is used to bend light rays and produce images.

QUESTIONS

A

1. What is the speed of light?

2. What is diffuse light?

3. Give an example of: (*a*) a transparent substance; (*b*) an opaque substance; (*c*) a translucent substance.

4. What is meant by the reflection of light?

5. Where is the image formed in a plane mirror?

6. Name three optical devices that contain lenses.

7. For each of the following blanks supply the word *transparent, translucent,* or *opaque:*

- (*a*) Cellophane is —?—.
- (*b*) Coal is —?—.
- (*c*) Water is —?—.
- (*d*) Wax paper is —?—.

8. Complete each of the following by supplying the correct word or phrase.

- (*a*) Light is refracted when it passes through the —?— of a magnifying glass.
- (*b*) A convex lens is —?— in the middle than at the edges.
- (*c*) When light travels from a more dense substance to a less dense substance it is bent —?— the perpendicular.

9. Determine which of the following statements are true and which are false. Then correctly reword the false ones.

- (*a*) When light is reflected from a smooth surface the angle of incidence equals the angle of reflection.
- (*b*) Light always travels in curved lines.
- (*c*) Light transmitted by a perfectly smooth piece of glass is called transparent light.
- (*d*) Light will not pass through an opaque object.
- (*e*) Lenses are used to refract light.
- (*f*) A plane mirror always forms a real image.

B

10. Describe two methods of concentrating light at a point.

11. Describe an experiment that shows how light is refracted.

12. What is the nature of the image formed by an object in front of a convex mirror?

13. Is the image in a plane mirror real or virtual? Give a reason for your answer.

14. An object is placed 3 inches in front of a lens with a focal length of 2 inches. Show by a diagram where the image will be formed, and describe the image.

15. An object is placed 3 inches in front of a lens with a focal length of 5 inches. Show by a diagram where the image will be formed, and describe the image.

The project for this chapter will be found on the next page.

PROJECT

To Make a Periscope. A simple periscope is easy to construct. It can be used for looking over fences and to see over other people's heads in a crowd.

Make a long rectangular wooden box out of thin wood. It should be about 2 or 3 feet long (the shorter the tube, the greater the field of vision) and about 4 or 5 inches square. Cut two square holes close to the ends on opposite sides of the box and glue two mirrors into these holes at a 45-degree angle, as shown in Fig. 41–20. You can use cheap mirrors and have them cut to size at a hardware store. The whole apparatus can be painted black, both inside and out, and a handle can be attached to each side near the base.

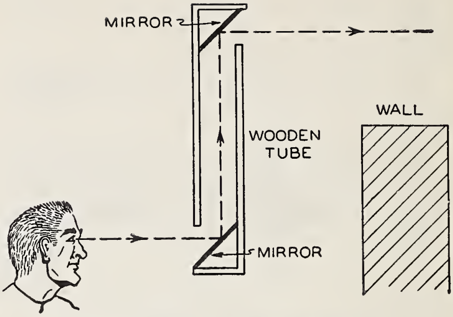


Fig. 41–20. A simple periscope.

Chapter 42

OPTICAL INSTRUMENTS

The principles of reflection and refraction are applied in optical instruments. In this chapter we shall study some of these instruments—the camera, the human eye, the microscope, and the telescope—and in the next chapter we shall discuss the spectroscope.

A Simple Camera. A simple, inexpensive camera consists of a light-tight box with a convex lens mounted at one end and a photographic film at the other (see Fig. 42–1). A shutter, mounted in front of the lens, is opened only at the instant a picture is being taken. At this instant light from the objects being photographed passes through the lens and is bent to form an image on a film coated with a chemical that is sensitive to light. When properly developed, the film holds a permanent impression of the image, thereby forming a negative.

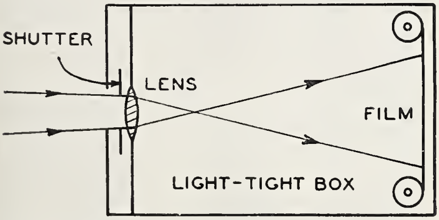
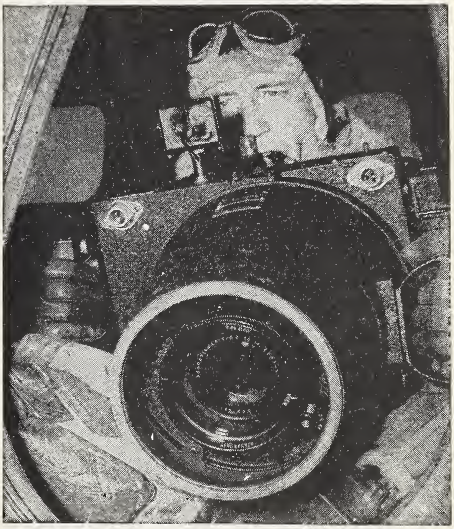


Fig. 42–1. The path of the light rays in a simple camera.

All cameras, regardless of their price, operate in this manner, but in order to get pictures under poor conditions, various devices are added and better lenses are used.

Many people find it interesting to carry through the whole photographic process by developing their films and printing their pictures themselves. Although the process is fairly involved, the principles can be presented simply.



Courtesy U.S. Navy

Fig. 42–2. An aerial camera.

A film usually consists of a plastic strip coated with a layer of gelatin. Dispersed in the gelatin are small light-sensitive crystals of a substance such as silver bromide. When light hits the crystals a change occurs in their structure, and they can be reduced to metallic silver more easily after exposure than before. The metallic silver is black and makes the photographic negative.

In taking a picture, the film is *exposed* for a moment by opening and closing the shutter. It is then *developed;* that is, in a special solution the exposed parts are reduced to silver. The unexposed parts must be dissolved with *hypo* (sodium thiosulfate) so that they will not turn black after a long time. After the film has been washed and dried, it is a *negative,* showing the picture in reverse, as in Fig. 42–3A.

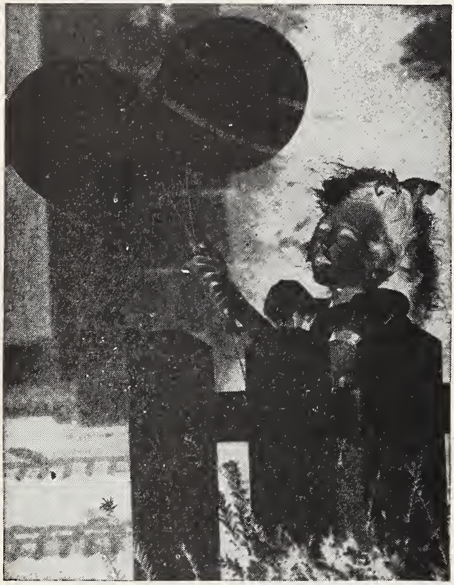


Fig. 42–3A. A negative.

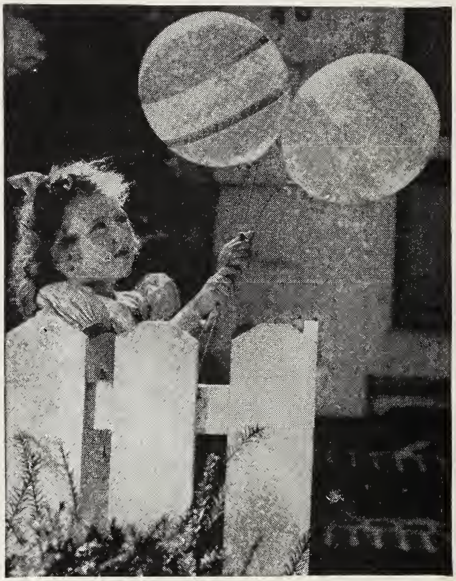


Fig. 42–3B. A positive print.

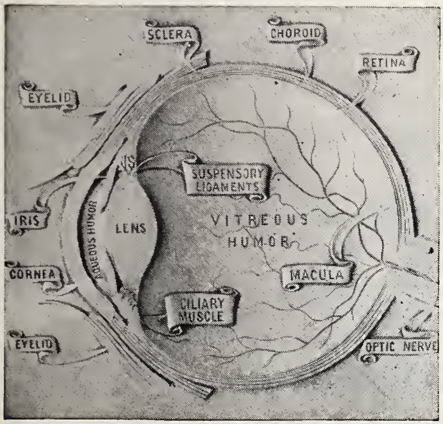
A *print,* or ordinary picture, is made by placing the negative in contact with a piece of photographic paper coated with a light-sensitive emulsion similar to that on film and then exposing the paper to light through the negative. This paper is then developed, fixed in hypo, washed, and dried. If all steps have been performed correctly, the print will be a picture, called a *positive,* of the original scene to which the film was exposed.

The Eye. The human eye is the most sensitive of all optical instruments. Like the camera, the eye is a light-tight compartment, but it is spherical in shape. Like the camera, it has a lens in front and a sensitive film at the back on which images are focused.

But here the similarity between the eye and the camera ends. The film of a camera is shielded from light until the instant the exposure is made. After the exposure the picture must be developed. Moreover, the film can take only one exposure; otherwise, it is spoiled. The sensitive film of the eye, on the other hand, receives impressions continuously, and these impressions are "developed" instantly. In this respect the eye is more like a television camera than like a photographic camera. The light-sensitive film in the eye is called the *retina.*

The Retina. The retina is a delicate film about 1/50 inch thick. It consists of the cells of nerve endings that are sensitive to light, and it is connected to the brain by "transmission lines" which make up the *optic nerve.*

The cells at the center of the retina are cone-shaped and are called *cones*; those along the edges are rod-shaped and are called *rods.* The cones and rods serve different purposes. With the cones we see details and distinguish colors during the daytime. But the cones do not function in darkness, and on a very dark night the center of the eye is blind. The rods, on the other hand, do not see details sharply, but they are far more sensitive to light than the cones. At night, therefore, they respond to the faintest light, so that, if the atmosphere is clear, we can see a candle flame as far as 14 miles away. Thus we really have two kinds of vision—day vision and night vision.



Courtesy Bausch and Lomb Optical Co.

Fig. 42–4A. The eye.

How sensitive are our eyes? With how little light can we see? Though we can easily see by full moonlight, our vision is not keen; grass and leaves of trees, for example, appear gray, not green. Full moonlight is only 1/50 foot-candle. Starlight is even dimmer—it may be only one-thousandth as bright as moonlight—yet we see by it, although the outlines of objects are blurred.

As we step from a well-lighted room into the darkness of night we are at once aware of the different responses of the rods and cones. The cones no longer act, and the rods require some minutes to regain their sensitivity, so that we become temporarily blind.

Most animals have both day and night vision, but some have only one kind. Owls and mice, for instance, have only night vision, and are therefore active at night. Many birds, on the other hand, have only day vision. When it gets dark, chickens go to roost, and hawks go to their nests.

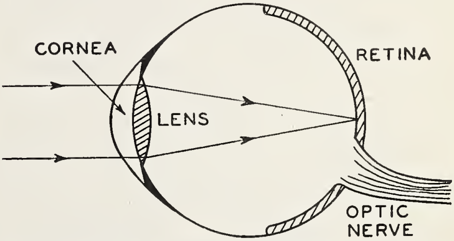


Fig. 42–4B. The lens of the eye acts like the lens of a camera, the retina of the eye like the film in a camera.

Eye Defects. The eye is a complex mechanism. It is not surprising, therefore, that all its parts do not always function perfectly. Few of us are entirely free of eye defects, although our particular defect may be minor. To correct nearsightedness, or farsightedness, or astigmatism, we wear glass lenses.

In normal vision the muscles of the eye flatten or round out the lens to change its focal length so that a sharp image of either a distant or a close object is formed on the retina. In nearsighted persons, however, the eyeball is so long that the image of a distant object is formed in front of the retina and is therefore blurred. Objects that are close to the eye can be seen clearly, since the image of nearby objects is formed well behind the lens. Nearsightedness can be corrected with concave lens placed directly in front of the eye, as shown in Fig. 42–5. Farsighted persons cannot see clearly objects that are very close to the eye because the eyeball is so short that the image forms behind the retina, as shown in Fig. 42–6. This condition can be corrected with a convex lens. If you wear glasses, are they concave or convex? Are you nearsighted or farsighted?

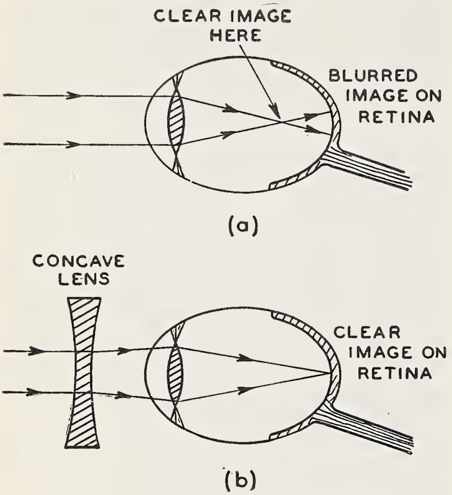


Fig. 42–5. The eyeball in a nearsighted eye (*a*) is too long and gives a blurred image of distant objects on the retina. Glasses with concave lenses (*b*) will correct nearsightedness.

In some eyes the *cornea*, which is in front of the lens, is not curved equally all over its surface. This causes an image to be formed that is sharper in one direction than in other directions. This defect is called *astigmatism*. It is the most common eye defect, although in many cases it usually is not serious enough to require correction. However, it too can be corrected by glasses. You can test your eyes for astigmatism by using Fig. 42–7. Slowly turn the book around while looking at the diagram. If one set of lines first looks sharper than the others and then, with further turning, becomes blurred while the other lines become sharp, you have astigmatism.

The Microscope. The microscope has made it possible for man to see and study objects too small to be seen by the unaided eye. A good microscope may increase the apparent size of small objects as much as two thousand times. It is used in many different scientific fields, such as biology, geology, metallurgy, chemistry, and medicine. The geologist examines a thin slice of rock to discover its nature; the metallurgist examines the structure of steel to predict its properties; the biologist examines bacteria to learn about the control and prevention of disease.

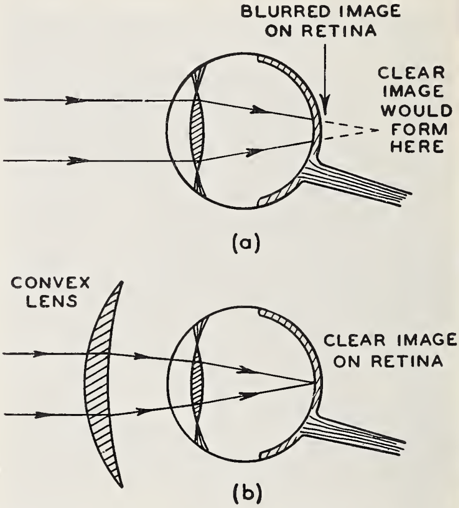


Fig. 42–6. The eyeball in a farsighted eye (*a*) is too short and gives a blurred image of nearby objects on the retina. Glasses with convex lenses (*b*) will correct farsightedness.

Fig. 42–8 shows the construction of the microscope. The *objective lens* is very small, and the microscope is adjusted so that the object is just *outside* the principal focus of the lens. This forms an enlarged real image, and

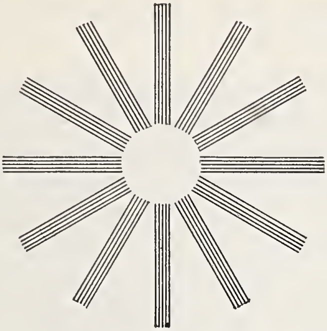


Fig. 42–7. A chart to test for astigmatism.

this image serves as the object for the *eyepiece,* a larger convex lens which is in such a position that the real image is just *inside* its principal focus. The final image seen by the eye is thus a magnified virtual image. Notice that this final image is inverted with respect to the original object, and objects therefore appear to be upside down.

TELESCOPES

There are two kinds of telescopes—astronomical and terrestrial. In an astronomical telescope, as explained below, everything is seen inverted. Since such telescopes are used mainly in photographing heavenly bodies, this is not important. A terrestrial telescope, on the other hand, must give an erect image to avoid confusion when observing ships and other objects on the surface of the earth. It therefore has a lens between the objective and the eyepiece to make the image erect.

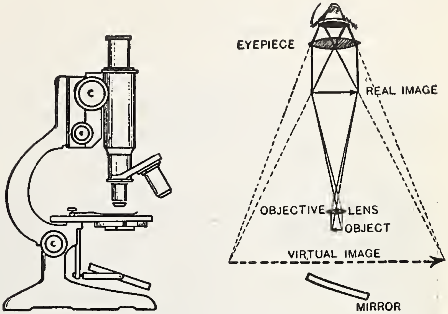


Fig. 42–8. Formation of image in a microscope.

Refracting Astronomical Telescopes. Fig. 42–9 shows an astronomical telescope that uses a lens for an objective and is called a *refracting* telescope. Since the object is always at a great distance from the lens, the light from the object comes to the lens in nearly parallel rays, giving a diminished real image at the principal focus of the large objective lens. This image is then viewed, as in a microscope, by a smaller eyepiece lens that forms an enlarged virtual final image, as shown in the diagram.

Reflecting Astronomical Telescopes. The first reflecting telescope was built by Sir Isaac Newton in the 17th century. Instead of an objective lens this type of telescope employs a concave mirror for collecting light waves. In principle modern telescopes are the same as Newton's, but in size they are giants by comparison.

Since a lens must be accurately ground on *both* faces, it is difficult to make large accurate lenses for refracting telescopes. A mirror

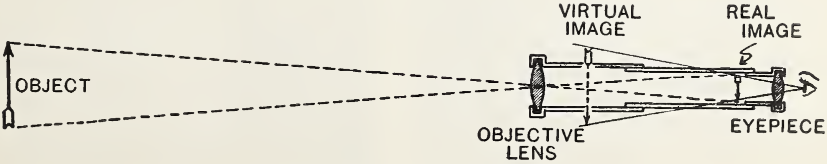
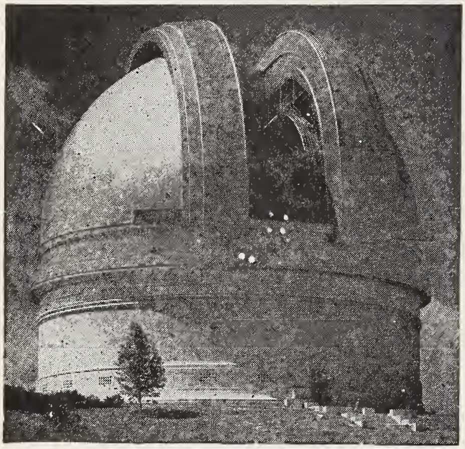


Fig. 42–9. A diagram of a simple refracting astronomical telescope.

needs to be ground accurately on one side only and then silvered. Therefore the largest modern astronomical telescopes are reflecting and use a concave mirror instead of a convex lens.

The Camera Attachment. Large astronomical telescopes, whether refracting or reflecting, are rarely used for direct observation; they are used with cameras. There are several reasons for this. Unlike observations made by one astronomer, a photographic plate makes pictures available to all astronomers who wish to study a particular region of the skies. Then again, the camera records many distant stars that the eye cannot see. The reason for this is fairly obvious. Suppose you are looking at a faint star through a telescope. No matter how long you look at it, the star does not become any brighter. This is not true of a camera. If light strikes a photographic plate for a few seconds, a certain amount of detail is recorded; and if the length of exposure is increased, fainter detail is recorded. That is, the cumulative effect of photographic exposure enables the camera to record many details that the eye cannot see.



E. Hage from California Institute of Technology

Fig. 42–10. The Mount Palomar Observatory, which houses the largest (200-inch) reflecting telescope in the world.

The Site of the Telescope. You probably have noticed that astronomical telescopes are usually located on high plateaus, far from cities. Do you know why? Telescopes should have an unobstructed view of the sky in all directions; and a high plateau, free from obstacles, such as mountain peaks, satisfies this condition. Moreover, the astronomer needs a clear, calm atmosphere, and at high altitudes there is comparatively little smoke and dust. At higher altitudes, too, there is less convection. Convection currents in the air make the stars twinkle—a condition the astronomer wishes to avoid.

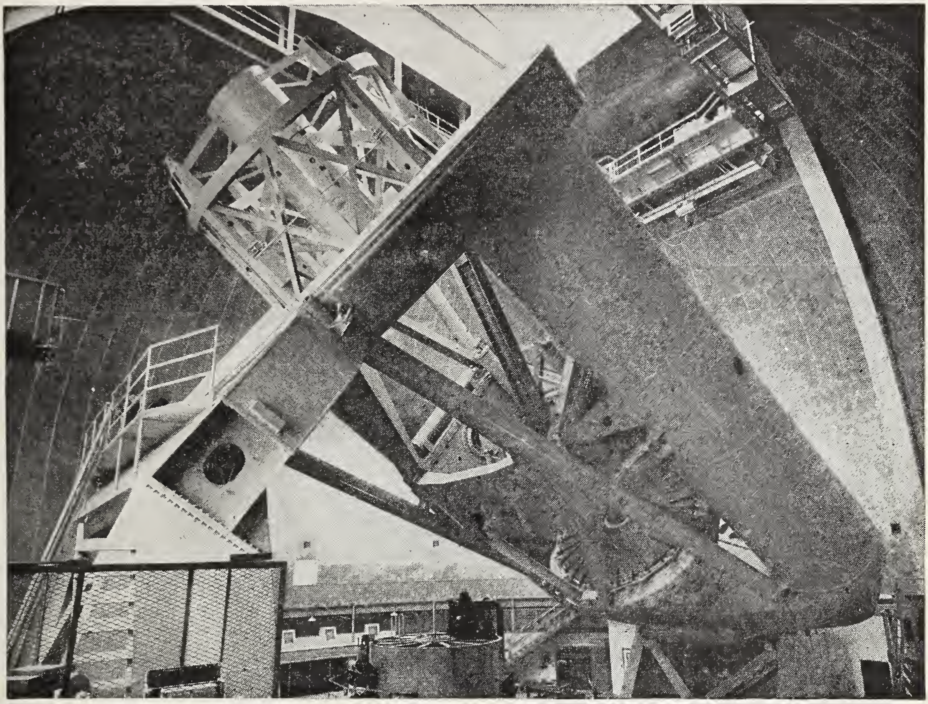
The Palomar Telescope. The world's largest telescope is on Mount Palomar, in southern California. It was completed in 1948. It is located on a broad plateau 5,600 feet above sea level. A gigantic steel structure, it weighs almost 500 tons and is housed in a steel-and-concrete dome which is 70 feet high.

The mirror in this telescope is a 15-ton disk of glass which was ground and polished to exact shape and then coated with a thin film of aluminum to reflect the light. It is 200 inches (or nearly 17 feet) in diameter, and it brings the light to a focus as shown in Fig. 42–12. This arrangement does not need a tube, but simply a supporting framework. A cylindrical chamber about 6 feet in diameter is suspended near the focus. Here the astronomer sits with an eyepiece, through which he checks the field of the telescope, and a camera.

The mirror is essentially a light-catcher. The larger the mirror the greater the amount of light brought to the eye or photographic plate. We have already stated that in total darkness the unaided eye can see a candle flame 14 miles away. Viewed through the 200-inch telescope, the same candle flame would be visible 14,000 miles away; and with a photographic plate, the telescope could "see" the candle flame 40,000 miles away.

The Palomar telescope has the power of a million eyes. It took twenty years to build it at a cost of more than ten million dollars. What is the purpose of this colossal observatory?

For thousands of years man has been trying to understand the universe he lives in. At one time he believed that the earth was the center of the solar system, and that the universe comprised the 2,000 stars visible to the naked eye. Astronomical instruments have revealed many facts about the universe. But there is still much man wants to know: Is the universe expanding? Is the earth the only place where intelligent life exists? Or are there other solar systems, among the millions of suns, with planets that can support life? Astronomers believe that Palomar will solve some of the mysteries of the universe. Some of these fundamental problems in astronomy will be discussed in a later chapter.



E. Hoge from California Institute of Technology

Fig. 42–11. The Mount Palomar telescope. The 200-inch mirror (lower right-hand corner) is covered to protect its delicate surface. The eyepiece is located in the cylindrical tube in the upper left-hand corner.

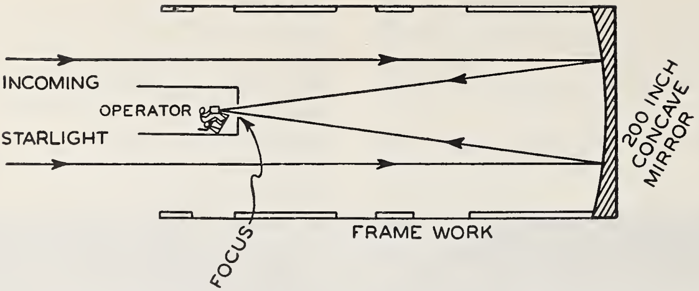


Fig. 42–12. A simplified diagram of the path of the light rays in the Mount Palomar telescope. Compare this picture with Fig. 42–11.

THINGS TO REMEMBER

A simple *camera* consists of a shutter, a lens, and a light-sensitive film mounted in a light-tight box.

The most important parts of the *human eye* are a *lens* and a light-sensitive surface called the *retina.*

A *microscope* contains a small *objective lens* and a larger *eyepiece.*

A *refracting astronomical telescope* contains a large *objective lens* and a smaller *eyepiece.*

A *reflecting astronomical telescope* contains a large *objective mirror* and a small *eyepiece.*

Most astronomical telescopes are used *with cameras* to increase their sensitivity.

The *Mount Palomar* telescope has a 200-inch concave mirror objective.

QUESTIONS

A

1. Name three optical devices that contain lenses.

2. What is the purpose of the shutter in a camera?

3. How does a camera resemble the eye?

4. How does a camera differ from the eye?

5. What is nearsightedness, and how can it be corrected?

6. What is farsightedness, and how can it be corrected?

7. What is the purpose of the objective lens in a refracting telescope?

8. Why should astronomical telescopes be located far from cities?

9. What is the difference between an astronomical telescope and a terrestrial telescope?

10. What are the principal parts of a microscope, and what is the purpose of each?

11. Name four fields in which a microscope is used.

B

12. What is astigmatism, and how can it be corrected?

13. Draw a diagram of an astronomical telescope showing how and where all images are formed.

14. Draw a diagram of a microscope showing how and where all images are formed.

15. Draw a diagram of: (*a*) a simple camera; (*b*) the eye.

16. What is the advantage of using a camera on an astronomical telescope?

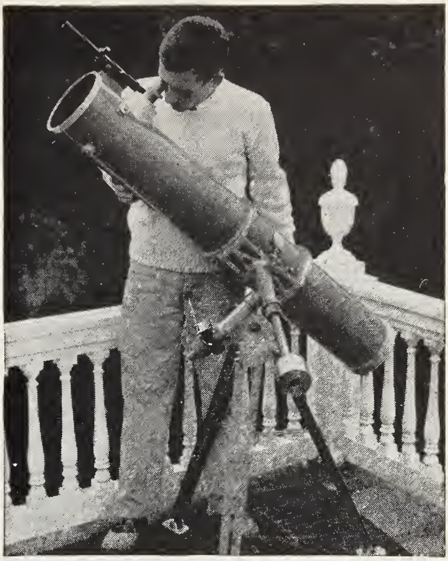
17. How can the spending of thousands of dollars to build the Palomar telescope be justified?

18. What is the function of the rods and cones in the human eye?

PROJECT

Constructing a Small Telescope. You can make a 6-inch reflecting telescope that will enable you to see a thousand times as many stars as you see with the naked eye. Information about materials and methods of grinding mirrors and constructing telescopes can be found in *Sky and Telescope Magazine,* published by the Sky Publishing Corporation, Harvard Observatory, Cambridge, Massachusetts.

Some amateur telescope-makers are organized into clubs. They are friendly to the newcomer and will help him get started on the road to telescope-making. If you are interested in astronomy, get in touch with one of the amateur astronomical societies. Some of these societies have members who possess telescopes; others have fewer members and less equipment. But all are willing to help the young astronomer. Some groups are interested in special fields, such as the observation of sunspots or variable stars. Such observations can be made with simple telescopes that you can construct yourself.



E. P. Little

Fig. 42–13. A 6-inch reflecting telescope. The whole telescope, including the grinding of the 6-inch concave mirror, was constructed by an amateur astronomer.

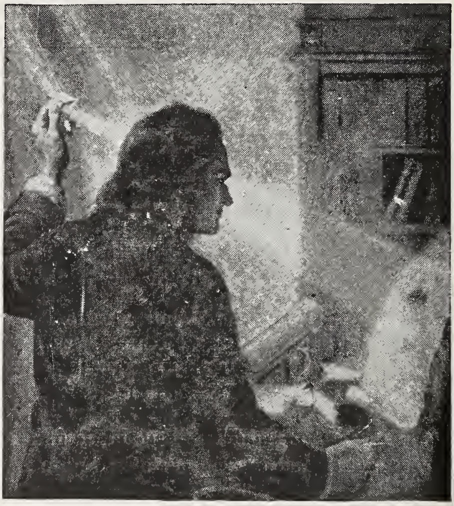
Chapter 43

WHAT IS COLOR?

When we see the colors of a sunset or of flowers, or of an outcrop of pink granite or red sandstone, or of an apple tree in spring, or of maple leaves in autumn, we realize that much of the beauty of nature is due to color. It would be a drab world indeed without color.

Birds can see colors, and some insects, such as bees and butterflies, can also see them. But there is reason to believe that most other animals, like dogs and horses for example, see only black and white. The retina of a horse's eye is somewhat like ordinary photographic film that is sensitive only to black and white. The retina of the human eye is more complex; it can be compared to color film in that it contains cells sensitive to colors as well as to black and white. But some people are unable to distinguish certain colors. They are said to be color-blind. Color-blindness is ten times as frequent in men as in women. The commonest form of color-blindness is the inability to distinguish red from green. Since these colors are used for traffic lights, all engineers on railroads are carefully tested for color-blindness. Because many automobile drivers cannot distinguish red from green, traffic lights on highways often have small amounts of other colors besides red or green so that they can be properly distinguished by color-blind people.

Newton's Investigation of Color. The nature of color was first investigated by Sir Isaac Newton in the 17th century. Newton allowed a beam of sunlight to pass through a narrow slit in the window shade of a darkened room so that it gave a patch of light on the opposite wall. He then held a glass prism, pointing it downward in the beam of light, and, to his amazement, the white patch disappeared and a long band of color appeared on the wall above the patch. The band was made up of various colors: red at the bottom, then orange, yellow, green, blue, and, finally, violet at the top. Such a band of colors is a *spectrum.*



Courtesy Bausch and Lomb Optical Co.

Fig. 43–1. An artist's conception of Newton's experiment in which Newton split up the white light into its separate colors by a prism.

Newton's classic experiment is very important. Let us make a similar observation ourselves with slight changes in the procedure.

Demonstration 43–1. Formation of a Spectrum.

Do this experiment in a dark room. Cover the lens of a flashlight with a piece of black paper cut with a slit that allows only a narrow beam of light to pass through. Place a glass prism on a stand near a white cardboard screen and direct the beam of light toward the prism. Rotate the prism on its vertical axis until a band of colors appears on the screen, as shown in Fig. 43–2.

Newton wondered how a glass prism could form a spectrum. He concluded that white light is really a mixture of many colors and that the different colors are bent, or refracted, by different amounts as they pass through a glass prism, violet being refracted the most and red the least. It is the difference in the amount of bending that causes the colors to separate.

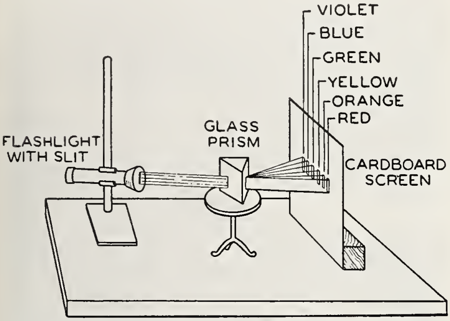


Fig. 43–2. Splitting up white light by a prism.

The glass prisms on "crystal" chandeliers are intended to break up the white light into the colors of the spectrum. But glass is not the only substance that separates white light into its constituents. A diamond, for example, bends the light rays even more than glass. Thus it sparkles with brilliant reds, greens, and blues. The most familiar example, however, of the breaking-up of light is the rainbow. This is nature's spectrum. It is formed when sunlight is separated into its colors by drops of water.

The Rainbow. When sunlight enters a raindrop the white light is refracted as it goes from air to water. It is then reflected inside the drop, and refracted again as it emerges from the drop. The violet light is refracted more than the red light; when the light emerges, therefore, the colors of the spectrum are separated just as in a prism.

The rainbow appears as a semicircular arc of light in the direction opposite the sun. To see it, you must therefore have your back to the sun. It is only the raindrops along this particular arc that send back the spectrum colors to the eye. The raindrops outside the arc also split up the sunlight, but the colored rays that emerge do not travel in the direction of your eye. A person standing in a different place will see the spectrum produced by some of these other drops of water. In other words, each person sees his own particular rainbow. In the same way when you stand near a fountain or a garden spray with your back to the sun, you may see a miniature rainbow produced by the drops of water in the spray.

Sometimes a faint circular "rainbow" can be seen around the moon at night. This has often been taken as a weather sign indicating approaching rain. Though no single sign can foretell the weather with certainty, this particular sign has a good basis in fact. The "rainbow," or halo, as it is more properly called, is caused by the refraction of the moon's light by tiny ice crystals of a particular shape that occur in thin cirrus clouds several miles above the earth. As we have already seen in Chapter 19, these clouds often precede a warm front, and a warm front usually brings rain.

Color of Objects. The spectrum colors do not include all the colors you are familiar with; neither brown nor purple, for instance, is a spectrum color. The spectrum bands are called *pure* colors because they cannot be further separated. Only rarely do we find these pure colors in nature; the colors in nature are usually mixtures, like purple, for example, which is a mixture of red and blue.

This brings us to the question: What causes the color of objects? Why is grass green and blood red? Strangely enough, an object is colored because it removes, or *absorbs*, something from white light. It absorbs some colors and *reflects* others. The colors that are absorbed are "lost" in the form of heat, and the colors we see are only those that are reflected. For instance, if sunlight falls on a red rose, the blue and green are absorbed; whereas the red, orange, and a little yellow are reflected. The rose therefore appears red. On the other hand, a blue iris absorbs the colors at the red end of the spectrum and reflects only those at the blue end. The iris therefore looks blue.

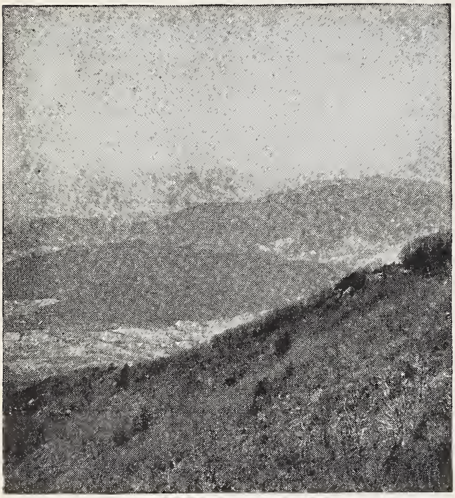


Fig. 43–3A. This photograph was taken without a color filter. Note that the sky appears uniformly gray and that no clouds are visible.

It follows from this explanation that a rose can appear red only if there are red rays in the light that illuminates it. In other words, *the color of an object depends on the nature of the substance itself and also upon the light that falls on it*. Let us illustrate this point in the following demonstration.

Demonstration 43–2. The Color of Objects Illuminated by Light of Different Colors.

In a darkened room set up the apparatus used in Demonstration 43–1 and hold a piece of red yarn in the beam coming from the prism. Hold the yarn so that it is illuminated only by blue and violet light. What color does it appear to be? Now examine a piece of blue yarn in the red part of the spectrum. In both cases the objects appear black. The red wool appears black because in the blue light that illuminates it there are no red rays which the wool can reflect to the eye. Why does the blue wool appear black in red light? Now examine the red wool in green and in yellow light and try to explain the color of the wool.

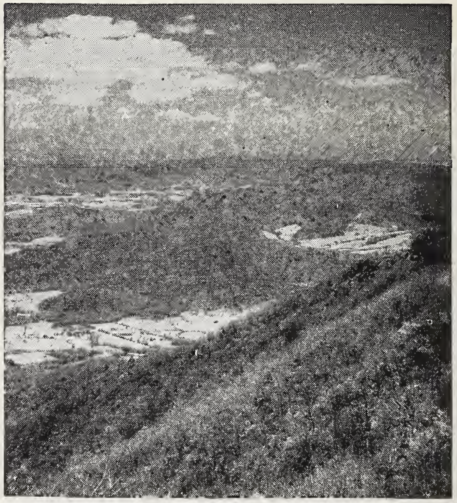


Fig. 43–3B. The same scene as Fig. 43–3A, photographed with a yellow filter in front of the camera lens. Note how the use of the color filter brings out the contrast between the white clouds and the dark (blue) sky.

Next examine the red and blue yarns in the light of a sodium flame (see Dem. 40–3). This flame gives only yellow light. What is the color of each piece of yarn? How do you explain this color?

Many dyes reflect more than one color. If, for example, a red tie with yellow stripes is viewed under sodium light, the red part will appear dark yellow, not black as one might expect. This is because the red dye reflects some orange and yellow as well as red. Examine a brightly colored tie in the sodium light. Can you explain the result?

It should now be plain why colors do not appear to be quite the same in artificial light as in sunlight. Two colors that match under artificial light may not match in daylight. A blue color, for instance, looks darker in artificial light than in daylight because there is less blue to be reflected in artificial light. Again, we find that a red color appears more intensely red in artifical light than in daylight. Can you explain this?

A yellow filter (a piece of glass that is transparent to all but blue light) is often used on a camera to bring out or emphasize clouds in landscape photographs. All colors are reflected by clouds, but there is only blue in the light from the blue sky. Thus, in a photograph taken using a yellow filter, clouds will stand out sharply against an almost black background of sky.

The Color of the Sky. If the earth had no atmosphere, the sky would be jet-black in the middle of the day. The sun would appear as a dazzlingly brilliant white orb, and all the stars would be easily visible as bright points of light in the black sky. Actually, the sky is so bright that it obscures all but the brightest planets and the moon. The blue light of the sky is sunlight that has been scattered or reflected in all directions by bits of dust and gas molecules in the atmosphere. In whatever upward direction we look, scattered blue light enters our eyes. The colors in the blue end of the spectrum, however, are scattered the most, and the green, yellow, and red light are affected very little. Since sunlight reaching our eyes is lacking in blue, the sun appears slightly yellowish rather than pure white.

On some days the sky appears less blue than on others. Sometimes, even when the sun is shining brightly, the sky is almost pure white rather than blue. This is due to a layer of thin cirrus high up in the atmosphere through which much of the sunlight passes unaffected. The water droplets in these clouds, however, are so much larger than air molecules that they scatter light from the red end of the spectrum as well as the blue end and we have all colors scattered, giving a white appearance to the sky.

Color of Sunsets. When the sun is setting, the light that comes directly to the eye travels through much more of the earth's atmosphere than when the sun is directly overhead (see Fig. 43–4). As a result, a great deal of light is scattered and the sun is dim enough to be viewed directly. It is a beautiful red or yellow,

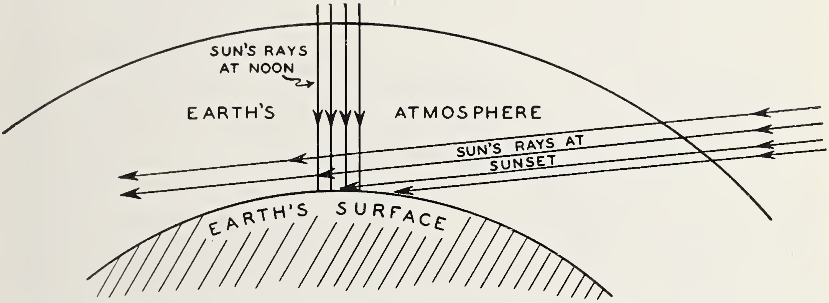


Fig. 43–4. The sun's rays travel through more of the atmosphere at sunset than at noon.

depending on the amount and the type of dust in the air which scatters the blue end of the spectrum.

All sorts of color combinations can result from scattering. A few clouds near the horizon will reflect the strongly colored sunset light and add to the beauty of the sunset. Some of the most beautiful sunsets are observed in the vicinity of forest fires, which fill the atmosphere with tiny smoke particles that cause a large amount of scattering. When the volcano Krakatoa, between Java and Sumatra, exploded in 1883 it hurled great quantities of volcanic dust into the upper air. The winds carried the dust to all parts of the world. Though the dust was so fine as to be completely invisible, it provided the whole world with exquisite sunsets for several years.

Color and Safety. Have you noticed that most of the highway traffic signs warning the motorist that he is approaching a crossroad, curve, stop street, or other danger point have black letters on a yellow background? The signs are so made because black and yellow is the most visible combination of colors.

Colors are used also to prevent accidents in large factories. At one time all machinery was painted a dull gray or black that did not show dirt and grease. In modern factories, however, the parts of a machine that must be watched constantly are painted a soft color to reduce eyestrain, while moving parts or controls are painted in bright, distinctive colors that attract the eye and warn of danger.

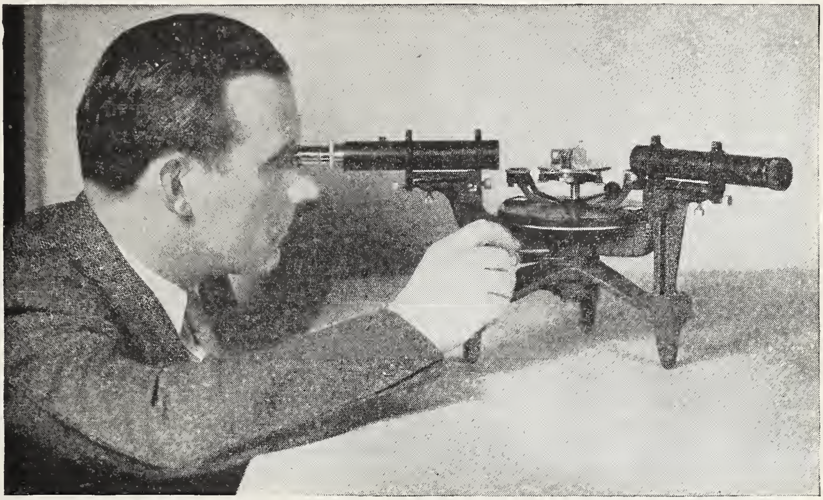
Light Waves. We have not yet explained how light travels through space. Scientists believe that both light and heat radiations travel through space in the form of invisible *waves*. In fact, we can picture the light radiated from a lamp, for example, as traveling outward in circular waves like the ripples formed when a pebble is dropped into the still water of a pond. But light waves, of course, travel at an enormous speed. Scientists also believe that the different colors of the spectrum are caused by light rays with different wave lengths. *Wave length* is the distance between two successive crests. For example, the crests of large ocean waves may be separated by 50 feet or more, whereas small ripples are much closer together and may have a wave length of only a few inches. Light waves are extremely close together and are as short as sixteen-millionths of an inch (0.000016 in.).

Of visible light, red light has the longest wave length and violet light the shortest. *The greater the wave length the faster the light travels through glass or water.*

Heat and Color. At this point you may be wondering how we get light waves of different colors. You will remember that the color of a hot object depends on its temperature; a yellow-hot object is hotter than a red-hot object, and a white-hot object is hotter than either. Hot objects, as we have already seen, are one of our primary sources of light. *The hotter an an object the more light of short wave lengths it emits.* Thus *a white-hot object appears white because it emits light of all visible wave lengths.* The sun, for example, gives off white light. The moon, unlike the sun, is cold, and is white only because it reflects all the colors of the light from the sun. Stars, like the sun, are very hot, and their color is due to their high temperature.

An object that is black absorbs all the colors that fall on it and reflects little or no light. Black therefore is not a color; it is simply the absence of light. A white surface is white because it is the best reflector of colors; indeed it reflects all colors. A white surface also reflects heat better than a surface of any other color. A black surface, on the other hand, absorbs all colors and also absorbs heat radiation. In other words, both the color and the heat radiation of a substance are the effects of waves differing only in wave length.

The Spectroscope. The spectroscope is an instrument that produces spectra. Newton's method of obtaining a spectrum was not satisfactory because the colored bands were not sharply focused. A better result is obtained when the light passes through a fine slit at the principal focus of a convex lens. If a prism is now interposed in the beam beyond the lens, the light is separated into its colors, producing a well-focused spectrum. In practice, the slit and lens are in a tube called the *collimator*, and the separated rays pass through a tube called a *telescope*. The prism is placed on a platform between the two tubes. The whole arrangement is called a *spectroscope*, a picture of which is shown in Fig. 43–5. Sometimes a photographic film is used to obtain a permanent record of the spectrum.



Courtesy American Optical Co.

Fig. 43–5. A simple spectroscope in use. The prism is on the platform in the center between the telescope into which the man is looking and the collimator (on the right).

Different Kinds of Spectra. If we use as the source of light an incandescent solid such as an ordinary electric light, we obtain a *continuous spectrum*; that is, we see all the colors from red to violet. But if we use a red neon light bulb as the source of light, we find that the spectrum consists mostly of red and orange and a few blue lines separated by dark spaces. This is called a *bright-line spectrum.* In other words, the spectroscope breaks up the red neon light and shows exactly what colors or wave lengths it consists of. The spectrum of the incandescent vapor of every known element has been examined, and it is found that *the spectrum of each element is different from that of every other element.* Thus each element, like each human being, can be identified by its own set of "fingerprints."

Some Uses of the Spectroscope. The spectroscope has given us an amazing amount of valuable information. The chemist uses it as a means of detecting minute traces of elements. If he has only a speck of an unknown substance, he heats it until it vaporizes. Then by examining its spectrum he can determine which elements are present. Such examinations have revealed sets of lines that were different from the spectra of known elements. In this way several new elements have been discovered.

The most fascinating research, however, has been the examination of spectra obtained from the sun and the stars. These spectra tell us the kind of atoms present in the stars and even the speeds at which the stars are moving. We find that the sun and stars contain the same kinds of atoms as the earth, and most of the atoms on the earth have been identified in the sun and the stars. During the last century, for example, astronomers discovered an abundant element in the sun that had not been found on the earth. Later investigations, however, showed that it *does* occur on the earth but only in rather small amounts. This is the element *helium*. (The word helium is derived from the Greek word *helios*, meaning "sun.")

The spectroscope is also used in medicine and in the detection of poisoning. The examination of a single drop of blood by a spectroscope reveals, for example, the presence of carbon monoxide. Carbon monoxide combines with the red coloring matter of blood to form a compound that can easily be recognized by its spectrum. Through the spectroscope, blood alone gives a single dark band in the yellow-green part of the spectrum; carbon monoxide combined with blood shows *two* bands instead of one in the same region.

Invisible Light. We have noticed that the spectrum extends from the red to the violet. At both ends it fades into darkness. This shows that there are no *visible* rays beyond the red or violet, but it does not prove that there are no rays of any kind beyond the visible spectrum.

Infrared Light. If we place a sensitive thermometer just beyond the red end of the spectrum, we discover the presence of heat radiation, usually called *infrared rays*. A hot iron in a dark room cannot be seen because it gives off no visible rays. But we can feel the heat of the invisible infrared rays, and with a special photographic plate sensitive to infrared rays, we can take a photograph of the iron and other objects in the dark room.

Infrared rays can also be used for photographing landscapes. This is done by placing in front of the camera lens a red glass filter that admits only red and infrared light and no other colors. Infrared rays can pierce fog and haze; they are not scattered by specks of dust in the air like ordinary visible light. The result is that distant objects are recorded much more clearly on the film than with ordinary light.

Ultraviolet Light. A photograph of the spectrum taken on an ordinary photographic plate shows a band extending well beyond the violet end of the visible spectrum. The rays in this band are called *ultraviolet rays*.

Infrared rays, which are longer than red rays, and ultraviolet, which are shorter than violet rays, can be called *invisible light*. Both can be photographed, for the camera has a wider range of vision than the human eye.

Some ultraviolet rays cause sunburn. They are useful, however, in treating certain diseases, such as rickets. The health-giving effects of sunlight are due largely to ultraviolet rays. Ultraviolet light also causes many types of chemical reactions.

The Electromagnetic Spectrum. The different kinds of rays we have discussed make up the *electromagnetic spectrum*. Fig. 43–6 shows the types of radiation that compose this spectrum. Note that the wave lengths of visible light occupy only a small portion of the whole range.

The longest waves in the electromagnetic spectrum are *radio waves*, which are discussed in Chapter 47. Waves that are slightly shorter than ultraviolet waves are called X *rays*. They are generated by a special kind of vacuum tube called an X-ray tube. Because they penetrate opaque materials, they are used to locate in the human body broken bones or foreign objects that cannot be seen otherwise. X rays are also used in industry for detecting cracks and flaws in metal castings. *Gamma rays*, which are even shorter than X rays, are given off by radioactive substances.

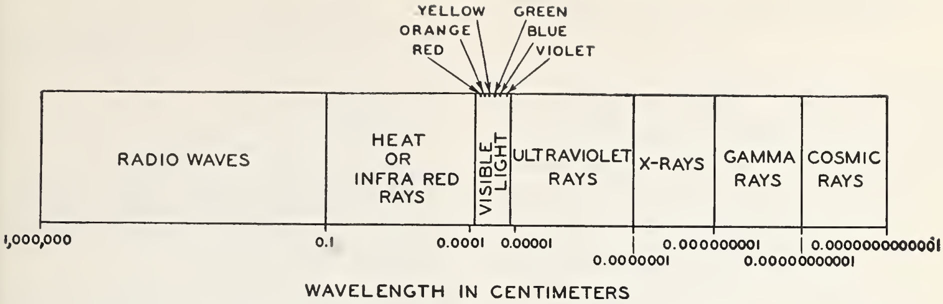


Fig. 43–6. The electromagnetic spectrum. The wave lengths are given in centimeters.

All these electromagnetic waves have similar properties. They all travel with the speed of light through a vacuum, and they can be reflected, refracted, and absorbed. The degree of reflection, refraction, and absorption, however, varies greatly with the wave length.

THINGS TO REMEMBER

White light can be split up by a prism into a *spectrum*, which consists of red, orange, yellow, green, blue, and violet light.

Different colors are composed of light of different wave lengths.

Of visible light, *red light* has the longest and *violet light* the shortest wave length.

Infrared light has a wave length that is too long to be seen by the eye.

Ultraviolet light has a wave length too short to be seen by the eye.

The *color* of an object is the color of the light it reflects when white light falls on it.

The sky is blue because some blue light from the sun is scattered by dust and gas molecules in the atmosphere.

Solids give off a *continuous spectrum* when they are incandescent.

Gases give off a *bright-line spectrum* when they are heated.

Each element, when in the gaseous state and incandescent, emits its own individual line spectrum.

A *spectroscope* may be used to identify the elements of which a substance is composed and to identify the elements in the sun.

QUESTIONS

A

1. What are the colors that make up white light?

2. How may white light be split up into the colors of which it is composed?

3. What is infrared light?

4. What is ultraviolet light?

5. What are X rays, and for what are they used?

6. Why is a blue dress blue?

7. Why is a red dress red?

8. Determine which of the following statements are true and which are false. Then correctly reword the false ones.

(*a*) Helium is an element that does not exist on the sun.

(*b*) One part of a spectroscope is called a *collimator*.

(*c*) Newton was one of the first scientists to investigate the nature of light.

(*d*) A piece of red-hot iron is red because it absorbs all colors except red, which it reflects.

(*e*) The moon shines by reflected light.

9. Why is black paint black?

10. How was helium first discovered?

11. What visible color has the longest wave length?

12. What visible color has the shortest wave length?

13. How does the spectrum of a gas differ from the spectrum of a piece of hot iron?

B

14. Describe the formation of a rainbow.

15. Why does a dark blue suit appear nearly black when seen under artificial light?

16. Determine which of the following statements are true and which are false. Then correctly reword the false ones.

(*a*) If infrared light is used to take a picture on a hazy day, the picture will be clearer than if ordinary light is used.

(*b*) Sunburn is caused by red light.

(*c*) The spectrum of neon gas is composed of many bright lines in the red end of the spectrum.

(*d*) A halo around the moon usually means clear weather.

17. (*a*) What is a spectroscope?

(*b*) How is it used?

(*c*) What is it used for?

18. A beam of light passes through a prism. What happens and why? Make a diagram.

19. How is the spectroscope used for detecting carbon monoxide poisoning?

20. Why is the sky blue?

21. What is the cause of beautifully colored sunsets?

PROJECTS

1. *Combining Colors to Make White Light.* Make a color wheel by cutting out a circle of cardboard about 6 inches in diameter. With a pencil divide it into three equal pie-shaped segments. Paint one segment bright red, another bright green, and the third bright blue. Now mount the wheel on a nail stuck through the center and, holding on to the nail, spin it rapidly by hand in a strong white light. The three colors should combine to give nearly white light, and the wheel, when spinning, should appear nearly white or light gray.

Newton split up white light into its component colors, whereas this experiment does just the opposite. The color from the two ends and the middle of the spectrum combine to give white light. We see white light here because of a property of the eye called *persistence of vision,* which means that when we see an object and it suddenly disappears or moves, we continue to see it in its original position for a fraction of a second after it has left. In this experiment a given colored segment rotates so fast that, because of this effect, we see a complete circle of that color. The same is true for each of the three segments, so the three colors combine in the eye to give the impression of a white disk.

2. *To Create an Artificial Rainbow.* On a sunny day, play a fine spray of water from a garden hose into the air, either by means of an adjustable nozzle or by holding the thumb over the end of the hose. With the sun at your back look at the spray and you should see a miniature rainbow.

3. *Scattering of Light as in a Blue Sky and Red Sunset.* Place a flashlight near a glass tumbler containing water. Darken the room and look through the tumbler directly into the light beam. Add a drop of milk from a medicine dropper into the water and stir. Notice that the light appears reddish-yellow. Add one or two more drops of milk and stir so as to increase the color effect. Holding the flashlight in place, look through the side of the tumbler. The light that now comes to your eye is bluish.

The milk particles have scattered the blue light so that the light which passes directly through the water appears reddish-yellow. (A solution of soluble starch may be used instead of the milk.)

REVIEW QUESTIONS ON UNIT 8

A

1. Complete each of the following statements by supplying the correct word or phrase.

(*a*) —?— lamps were used by the Romans and the Greeks.

(*b*) When light is reflected from a smooth surface the —?— equals the —?—.

(*c*) When light passes from air into water it is bent —?—.

(*d*) A white surface is a good —?— of light and heat.

(*e*) A microscope is used to magnify —?— objects.

2. Determine which of the following statements are true and which are false. Then correctly reword the false ones.

- (*a*) The light given off by a fluorescent lamp comes from a hot tungsten filament.
- (*b*) Sir Isaac Newton made the first electric light.
- (*c*) Refraction is the bending of light as it passes through a transparent substance.
- (*d*) A telescope may use either a lens or a mirror as an objective.
- (*e*) Kerosene lamps were invented before candles.
- (*f*) Light bulbs containing tungsten filaments are better than those containing carbon filaments.

3. Give one example each of an opaque, a transparent, and a translucent substance.

4. What is a spectroscope?

5. Complete the following statements by supplying the correct word or phrase.

- (*a*) Light travels in —?— lines.
- (*b*) A modern electric-light bulb contains a filament and —?—.
- (*c*) The image in a plane mirror is as far —?— the mirror as the object is —?—.
- (*d*) Parallel light rays that reflect from a curved mirror converge at the —?—.

6. Make three important statements concerning reflection in a plane mirror.

7. State the similarities and the differences between the operation of the eye and that of a simple camera.

8. How does the spectrum produced by a hot gas differ from that produced by a hot tungsten filament?

9. State an advantage and a disadvantage of the human eye over the camera.

10. What are infrared rays?

11. What are ultraviolet rays?

B

12. Name all the different kinds of electromagnetic waves in the order of decreasing wave length.

13. Why is the sky blue?

14. How may a spectroscope be used to determine carbon monoxide poisoning?

15. Describe, with the aid of a diagram, the construction and operation of a reflecting telescope.

16. What is the advantage of using a telescope with a large objective lens?

17. Why are sunsets red?

18. Describe the function of the lens and retina of the eye.

19. How does seeing in the dark differ from seeing in daylight?

20. What illumination would fall on a book 2 feet away from a 32-candlepower lamp?

21. Determine which of the following statements are true and which are false. Then correctly reword the false ones.

- (*a*) White light is composed of all the colors of the visible spectrum.
- (*b*) Incandescent lights are widely used because they give off no heat.
- (*c*) A rainbow is formed by reflection and refraction.
- (*d*) A spectroscope contains a concave mirror.
- (*e*) The image in a plane mirror is a real image.
- (*f*) The image in a plane mirror is in front of the mirror.

22. Show, by a diagram, how and where the image is formed in a plane mirror.

23. Show, by a ray diagram, how and where an image is formed by a convex lens when: (*a*) the object is outside the principal focus; (*b*) inside the principal focus.

24. If white light is passed through a simple convex lens, the red light will come to a focus a little farther from the lens than the blue. How can you explain this?

SUGGESTIONS FOR FURTHER READING

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Unit 9

COMMUNICATION

44. WHAT IS SOUND?
45. SOUND INSTRUMENTS
46. THE TELEGRAPH AND TELEPHONE
47. RADIO AND ELECTRONICS

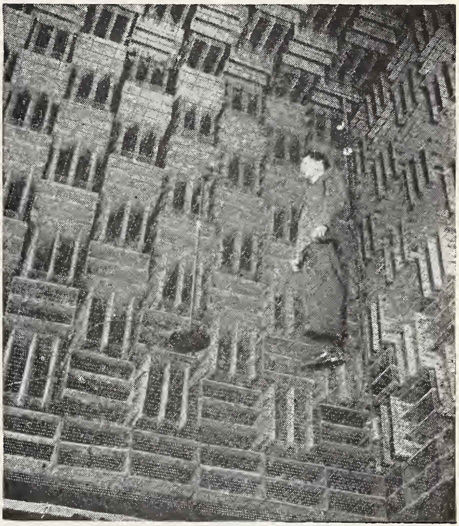
Chapter 44

WHAT IS SOUND?

Have you ever stopped to think that we live in a world of sounds? Without sound we would have difficulty in communicating with one another. Man depends so much on the spoken word that not being able to hear is a great hardship. We hear loud and objectionable noises as well as pleasing music and the voices of our fellow beings. At times we are not conscious of any sound at all, but even when all seems quiet there are sounds that we can just hear but not identify. In absolutely quiet surroundings, however, as in a soundproof laboratory, we can hear our own heartbeat and the faint rushing sound made by the blood flowing through our arteries and veins. In fact, the ear is almost sensitive enough to hear the faint sound made by the molecules of the air as they rush to and fro bombarding our eardrums.

How Sound Travels. Sound is a form of energy, and it travels from a source, such as a musical instrument, to our ear by invisible *sound waves.* Though all matter conducts sound waves, some substances are better conductors than others. Steel, for example, is a good conductor. Sponge rubber and fiber board, on the other hand, are poor conductors, since they absorb a great deal of the sound energy and convert it into heat energy. Sound waves cannot travel through a vacuum. Regardless of how loud a noise is on the earth, the sound can never travel beyond the earth's atmosphere and be heard on another planet.

The Speed of Sound. *Sound travels through the air at about 1,100 feet per second,* or 750 miles per hour; it travels faster through solids and liquids than through air. Its speed varies somewhat with temperature and pressure. The speed of sound is very much slower than that of light, which, you will recall, is 186,000 miles



Courtesy Bell Telephone Laboratories

Fig. 44–1. A soundproof room used in sound experiments. To eliminate all surfaces that would reflect sound, the walls, ceiling, and subfloor are lined with special sound-absorbing materials. The unusual floor resembles the hitting surface of a tennis racket and consists of high-strength steel wires strung under high tension between the walls.

per second. Thus when a ship, seen at a distance of a mile or so, blows its whistle, the puff of steam from the whistle is visible as the whistle cord is being pulled, but the sound is not heard until several seconds later. At track meets the official timers at the finish line of a 220-yard dash must start their stop watches the instant they see the puff of smoke from the starter's gun. They do not wait until they hear the shot, since it would not reach their ears until nearly half a second after the race had started.

Knowing the speed of sound, you can determine how far away an approaching thunderstorm is. All you need is a watch with a second hand. When you see a flash of lightning, measure the time between the seeing of the flash and the hearing of the thunder. With this time and the speed of sound, you can calculate how far you are from the lightning. Suppose, for example, you see a flash of lightning and 10 seconds later you hear the thunder. The light from the flash travels so fast that it takes practically no time to reach you, but the sound, traveling only 1,100 feet in one second, travels 1,100 × 10, or 11,000 feet in the 10 seconds. The thunderstorm is therefore about two miles away.

The Cause of Sound. *Sound is produced when an object vibrates.* The vibration of the object then sends forth sound waves in much the same manner that a stone thrown into calm water produces waves. The following demonstration will show that a tuning fork is vibrating when it gives forth sound waves although the vibrations are too rapid to be seen.

Demonstration 44–1. A Vibrating Tuning Fork.

Support a small pith ball by a thread so that it just touches one of the prongs of a tuning fork, as shown in Fig. 44–2. Holding the fork firmly at the base, strike the other prong with a small felt-covered wooden mallet. The fork vibrates and produces sound. Watch the pith ball.

You will notice that as long as the fork emits sound the pith ball keeps bouncing back and forth. This is because the vibrating prong of the fork strikes the pith ball every time it comes close enough, making it fly off through the air. When the fork no longer produces sound, the pith ball stops vibrating, showing that when there is no vibration there is no sound.

Sound Waves. What is the nature of the sound waves that carry sound energy from the source to our ears? Let us examine Fig. 44–3 and see what happens as the prong of a tuning fork vibrates in the air. As the prong moves to the right, it quickly compresses the air just in front of it. This *compression* is passed on to neighboring air molecules and travels outward at a speed of 1,100 feet per second. At the end of its swing, the prong moves to the left, leaving a partial vacuum behind it, which also travels outward, following the first compression, at the speed of sound. This partial vacuum is called a *rarefaction.* Then the prong moves to the right again and sends out another compression through the air. These compressions and rarefactions succeed one another many times a second and are called *sound waves* (see Fig. 44–4). They are always produced when an object vibrates in the air. Notice, however, that the molecules merely vibrate back and forth about their normal positions as the sound wave passes through them. It is only the sound *energy,* not

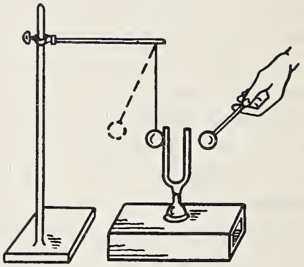


Fig. 44–2. A tuning fork vibrates to and fro when it produces sound, as shown by the motion of the light pith ball.

feet per second.
the molecules, that moves outward at 1,100

Wave Length and Frequency. Sound waves are often pictured by means of a graph or by

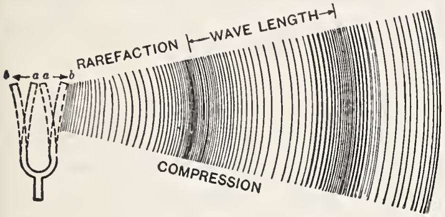


Fig. 44–3. How sound waves are produced by a vibrating tuning fork.

a diagram such as Fig. 44–5. The vertical axis represents the distance a given molecule is displaced from its normal position, and the horizontal axis represents the time at which this takes place. Notice the similarity between

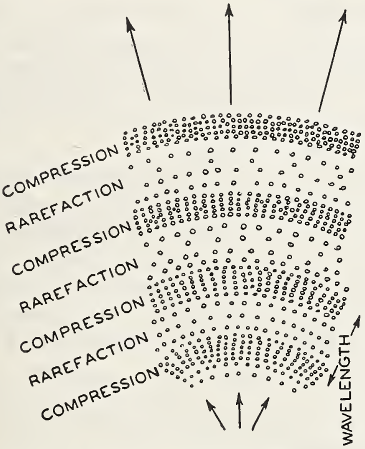


Fig. 44–4. A diagram of a moving sound wave. The compressions and rarefactions of the air molecules move out in all directions from the source at a speed of 1,100 feet per second.

this diagram and that on page 421 representing an alternating electric current. This similarity is of great importance, as you will learn in Chapter 46, where the telephone is discussed.

Another type of sound-wave graph is shown in Fig. 44–6, where the horizontal axis represents distance from the source. It represents sound waves at a single instant of time. The

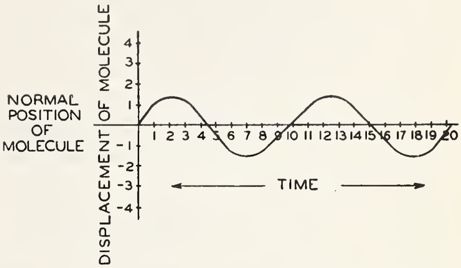


Fig. 44–5. A graph of a sound wave showing the position of a given molecule at different instants of time as it moves back and forth while a sound wave is passing.

distance between any two successive *crests* of the wave is called the *wave length*. This distance is found by dividing the velocity of sound by the frequency (the number of vibrations per second) of the vibrating object. This may be expressed by a formula, as follows:

$$\text{wave length} = \frac{\text{velocity}}{\text{frequency}}$$

For example, if a tuning fork vibrates 1,000 times per second, one crest will travel $\frac{1100}{1000}$, or 1.1 feet, from the fork before the next crest

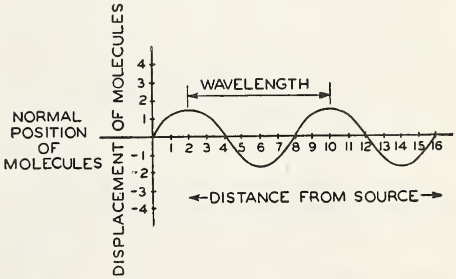


Fig. 44–6. A graph of sound wave showing the position of different molecules at different distances from the source at one instant of time.

is produced. The wave length is therefore 1.1 feet.

Pitch. When we say that the notes produced by a musical instrument are high or low, we are actually referring to the *pitch* of a note. Pitch is determined almost entirely by the number of vibrations per second produced by the source of sound. In other words, by varying the frequency (vib/sec) or the number of cycles per second (cycles/sec), sounds of different pitch are produced.

Demonstration 44–2. To Produce Sounds of Different Pitch.

Fix a toothed wheel to the shaft of a small variable-speed electric motor. Start the motor, and hold a stiff piece of cardboard or sheet metal against the teeth as shown in Fig. 44–7. Change the speed of the motor so that the wheel goes very fast and then very slow.

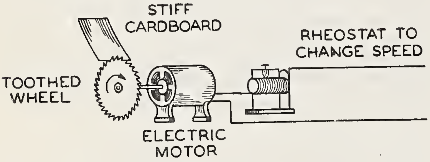


Fig. 44–7. Producing sounds of different pitch.

You notice that as the speed of the wheel changes, the character of the sound also changes. It does not become louder or softer; it changes in *pitch*. When the wheel spins rapidly, the card bounces from tooth to tooth many times a second, and a sound of high pitch is produced. When the wheel turns slowly, the number of vibrations per second of the card is reduced, and the pitch of the sound produced is low.

Audible Frequencies. The human ear is unable to hear sounds whose frequency is lower than about 20 cycles per second. This lowest audible frequency has a wave length of $\frac{1100}{20}$, or 55 feet. Very low frequencies, if they are strong enough, can be *felt* by the body but they cannot be *heard* as sound. Frequencies higher than 20,000 vibrations per second generally cannot be heard, nor can these high frequencies be felt. A frequency of 20,000 cycles per second represents a wave length of $\frac{1100}{20,000}$, or .055 feet, or a little more than half an inch.

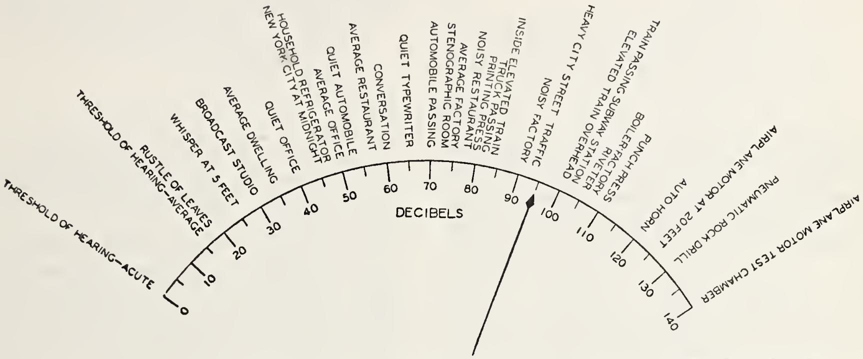
Human hearing is measured by an apparatus called an *audiometer*. This instrument can produce sounds of any pitch and intensity, or loudness. The person being tested listens in a quiet room while the operator of the audiometer produces a sound of very low pitch and intensity. The intensity is increased gradually until the person can hear the sound. The process is then repeated at higher and higher frequencies right through the audible range. From the data obtained the operator can determine the condition of a person's hearing.

Ultrasonics. Certain birds, dogs, and some other animals are able to hear sounds with a frequency higher than 20,000 cycles per second. There is a type of whistle not audible to a human being that can be heard several blocks away by a dog.

Frequencies too high to affect the human ear are called *ultrasonic* sound. Scientists have discovered that, because of their high energy, ultrasonic waves have many properties that audible sound waves do not have. For example, a piece of cotton, when held in front of a large ultrasonic generator, bursts into flame. The generator gives forth no audible sound and has no apparent effect on the human body, yet small animals would be killed by these vibrations.

Loudness and Decibels. The greater the distance through which a sound source vibrates, the more the air molecules are displaced and the louder the sound. The distance the molecules are displaced is called *amplitude*. Hence when we wish to describe the loudness or intensity of a sound, we often refer to its amplitude.

An instrument called a *sound-level meter* measures the amplitude of sound waves in units called *decibels.* Such instruments are used to investigate noise in factories and large offices and on busy city streets. Continuous exposure to noise can reduce human efficiency and cause fatigue, headaches, and even nausea. A great deal of effort and money has therefore been expended to reduce factory and street noises.



Courtesy General Radio Co.

Fig. 44–8. The decibel scale of loudness.

Sound Conditioning. Rooms whose walls, ceilings, and floors are constructed of hard-surfaced materials are likely to be noisy, because such materials reflect the sound waves and make the smallest sound easily audible. Architects use sound-absorbing materials in modern buildings. The sound-reflecting and sound-absorbing properties of the walls, ceiling, and seats of an auditorium determine the *acoustics* of the hall. If hard materials are used, there may be too much *reverberation,* or echo; that is, a sound will travel back and forth over the hall for several seconds before it dies out. This reverberation causes sounds to run together, giving a blurred effect to both voices and music. Too much absorption by sound-proofing material, on the other hand, will make a hall dead, and music will not have sufficient brilliance.

Reverberation can be demonstrated in a long quiet corridor with hard walls and floors. If you clap your hands, you can hear the sound for several seconds before it is completely absorbed.

THINGS TO REMEMBER

Sound cannot travel through a *vacuum.*

Sound travels at a *speed of 1,100 feet per second* through air.

Sounds are produced by *vibrating* objects.

The *frequency* or *pitch* of a sound is the number of vibrations per second.

The *ear* is sensitive to frequencies of from 20 to 20,000 vibrations per second.

Sound waves are alternate *compressions* and *rarefactions* of the air that travel at 1,100 feet per second.

The *amplitude,* or loudness, of sound is measured in *decibels.*

QUESTIONS

A

1. What is the speed of sound?

2. What is meant by the pitch of a sound?

3. What is meant by the loudness of a sound?

4. What is reverberation?

5. What is the range of audible frequencies?

6. A hunter fires a gun and the smoke is seen by a distant observer 3 seconds before the sound is heard. How far is the observer from the hunter?

7. How sensitive is the human ear to sound?

B

8. Is the speed of sound always 1,100 feet per second? Explain.

9. A gun is fired 300 yards from a tall cliff. The sound is reflected from the cliff as an echo to the person who fired the gun. How long a time elapses between the firing of the gun and the hearing of the echo?

10. Describe a demonstration that shows that the pitch of a sound depends upon the number of vibrations per second of the source.

11. What are ultrasonics?

12. Draw a graph of a sound wave in which the vertical axis represents the displacement of an air molecule and the horizontal axis represents the time.

PROJECT

To Measure the Velocity of Sound. This project is best done in the country by a small group under the guidance of a teacher. Borrow a stopwatch and a starter's gun from the athletic department. Find a straight stretch of road, half a mile or more in length. Measure the distance between two points on the road that are within sight of each other and as far apart as possible. The distance may be measured with an automobile. One group stays at one end with the stopwatch, and the other group, with the teacher, goes to the other end of the measured distance. The teacher then fires the gun so that its smoke can be seen by the student operating the stopwatch. When the student sees the smoke, he starts the watch, and when he hears the shot he stops the watch.

The velocity of sound can then be found by dividing the distance between gun and observer by the time between the sight of the smoke and the sound of the gun, as measured on the stopwatch. For most accurate results, the experiment should be done when there is little or no wind. Can you explain why wind could cause an error?

Chapter 45

SOUND INSTRUMENTS

We have seen that a vibrating tuning fork gives forth sound. When the fork is held in the hand, the sound it produces is not very loud. If, however, the base of the fork is pressed firmly against a large hard surface, such as a blackboard, the sound is much louder. The fork sets the blackboard in vibration at the same frequency as itself. The vibrations of the blackboard, called *forced vibrations*, then reinforce the sound of the fork and make it louder. In the same way the sounding board in a piano strengthens, or reinforces, the tones from the vibrating strings. Without the vibrations of a sounding board the sounds produced by striking the keys would be weak. Sound can be reinforced by any hollow box or chamber regardless of its shape. The box of a violin, for example, reinforces the sound produced by the vibrating strings.

Resonance. It has been found that a tube closed at one end can be used to reinforce sound. But it reinforces only a sound of a particular frequency. Such a tube is called a *resonant column*. The frequency or wave length to which it is resonant depends on its length. The following demonstration shows the relationship between the length of the column and the wave length of the reinforced sound.

Demonstration 45–1. A Resonant Air Column.

Fill a 100-cc. graduate with water. Over the top of the tube hold a vibrating tuning fork whose frequency is 440 cycles per second (the musical pitch of A above middle C, which is the standard for tuning musical instruments). Is the sound of the fork reinforced? Now pour out from 5 to 10 cc. of the water and again hold the vibrating fork over the graduate. Repeat this process until the sound is strongly reinforced. Now pour a little more water back into the tube and adjust the level until you have the maximum reinforcement. The air column in the tube is now a resonant length. It measures about 7.5 inches.

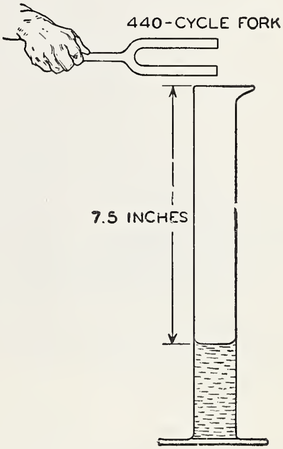


Fig. 45–1. A resonant column of air.

We have already seen that the wave length of a sound can be expressed by the equation $L = \frac{V}{F}$, where L is the wave length, V the velocity of sound, and F the frequency of the wave. By substituting the known values for V and F, we find that in this case $L = \frac{1100}{440}$ = 2.5 feet, or 30 inches. The length of the resonant column which reinforces this sound is 7.5 inches, which is one-quarter of 30 inches. We conclude, therefore, that *the length of a closed resonant column is exactly one-quarter the wave length of the sound it reinforces.*

Musical Instruments. A tube that is open at both ends also reinforces sound, but such a tube is a *half wave length long.* Both open and closed tubes are used in organ pipes and whistles. The sound is produced by a stream of air blown across one end of the air column. This air stream makes the large column of air in the tube vibrate at its resonant frequency. Wind instruments, such as flutes, clarinets, trombones, and tubas, produce sounds in a similar manner.

Vibrating strings also produce sound. Violin strings, for example, vibrate when stroked with a bow made of stretched horsehair. The shorter the string, the higher the frequency of vibration. A string is shortened by pressing it down firmly at different points along its length. A violin is tuned by turning a peg that tightens or loosens each string, thereby changing its pitch. *The greater the tension in the string, the higher is its frequency.*

The sound produced when a piano is played is also due to vibrating strings. Piano strings are set in vibration by *percussion,* that is, by blows from small felt-covered hammers. Drums, cymbals, gongs, and xylophones are also percussion instruments.

Quality. An organ pipe may produce at the same time two sounds having different frequencies. The sound with the lower frequency is called the *fundamental.* The other sound, called a *harmonic* or an *overtone,* has twice the frequency of the fundamental. Some sound sources produce many overtones of different frequencies and amplitude, or intensity. It is the number of overtones and their relative intensity that distinguish the sounds of different musical instruments. A clarinet and a trumpet, for example, sound different and are easily distinguishable even though they produce notes of the same fundamental pitch. This difference in the sound or tone of musical instruments is known as *quality. The quality of a sound is determined by the nature of its overtones.*

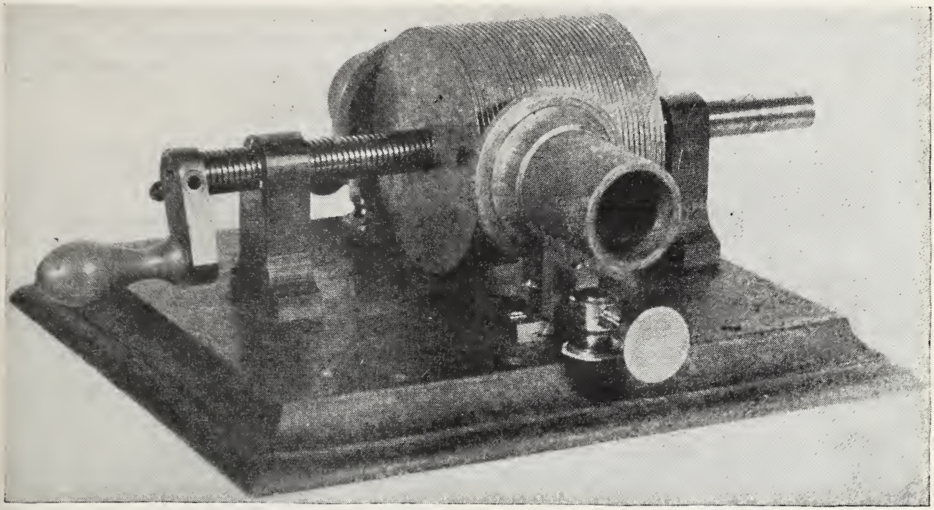
The Voice. The human voice produces sounds by means of vibrating tissue called the *vocal cords,* in the *larynx,* located in the windpipe. These cords are vibrated by air expelled from the lungs. The tension of the vocal cords is changed by muscular action, producing sounds of different pitch. The mouth and other passages act as resonating chambers. The quality of the voice can be changed by varying the shape and size of these cavities with the aid of the lips, tongue, and teeth.

The Ear. The inside of the ear consists of a series of passages ending in the *spiral canal,* which contains thousands of little hairs. Each hair has a different length, is resonant to a different pitch, and is connected to a nerve ending. When sound waves enter the ear they strike the *eardrum,* which starts vibrating. The vibration sets in motion three tiny bones which amplify the sound and conduct it to the spiral canal of the inner ear. There, only those tiny hairs vibrate that are tuned to the same pitch as the entering sound. Their vibrations are transmitted in the form of electrical impulses to the brain, where they are interpreted as sound.

The Phonograph. The phonograph was invented by Thomas Edison. Edison's first phonograph, shown in Fig. 45–2, consisted of a cylinder covered with tinfoil against which was pressed a sharp point or needle connected to a metal diaphragm. When the cylinder was rotated, the needle traced a spiral groove around the tinfoil surface. The voice, or other sounds near the diaphragm, made the needle vibrate so that the groove became a wavy line that exactly reproduced the sound variations causing it. After this "record" had been made, the needle was made to retrace the spiral and thus gave out a reproduction of the original sound.

The modern phonograph record has tiny wavy grooves that can easily be seen with a powerful magnifying glass in a strong light. The needle vibrations on a modern phonograph disc are converted into varying electrical currents, which are amplified by vacuum tubes and then reconverted into sound by a loud-speaker.

Wire Recording. Another method extensively used for recording sound is *wire recording*. In this system a reel of iron wire is fed past the poles of an electromagnet whose magnetic field is made to vary by changing the intensity of an electric current in exact correspondence with the sound waves to be recorded. This current is produced by a microphone and vacuum-tube amplifier. The changing magnetic field magnetizes the iron wire by varying amounts as it moves along, producing a reel with a permanent magnetic record of the recorded sound. When the wire record is "played," it is fed past a coil of wire, inducing a varying current in the coil that is amplified by vacuum tubes. The current is fed to a loud-speaker, thereby producing the sounds originally recorded on the wire. Plastic tape coated with powdered iron is often used instead of iron wire.



Courtesy Thomas A. Edison, Inc.

Fig. 45–2. Edison's first phonograph.

Although the reels are cumbersome and not as convenient as the more common disc records, wire recording has two advantages: it plays continuously for any length of time, and the wire can easily be run through a demagnetizer that "wipes off" the recorded sounds so that it can be used again. Radio stations often make wire recordings of programs to be broadcast at a later time.

THINGS TO REMEMBER

Overtones occur when more than one frequency is produced at the same time.

Most sound waves are very *complex* because of the presence of overtones.

The *quality,* or distinguishing sound, of a given musical instrument depends on the character of its overtones.

The *phonograph* was invented by Thomas Edison.

QUESTIONS

A

1. Who invented the phonograph?

2. How can sounds be reinforced?

3. A closed tube reinforces a sound whose wave length is 4 feet. How long is the tube?

4. How does the ear function?

5. How does the voice produce sounds?

B

6. To what frequency will the following columns be resonant: (*a*) a closed tube 5 feet long; (*b*) an open tube 2 feet long?

7. Why does a trumpet playing a certain note sound different from a saxophone playing the same pitch?

8. What is the difference between *forced* vibrations and *resonant* vibrations?

9. What is the length of an open tube that reinforces a sound whose frequency is 200 cycles per second?

PROJECTS

1. *To Measure the Speed of Sound by Resonance.* The fact that a closed tube must be a quarter of a wave length long to reinforce a sound of a given frequency can be used to measure the velocity of sound.

   Determine the length of a column resonant to a 512-cycle-per-second tuning fork by the method used in Demonstration 45–1. Find the velocity of sound by calculation from the formula $V = FL$. L will be 4 times the length of the resonant tube.

2. *To Construct a Monochord.* A monochord is a simple musical instrument similar to the earliest stringed instruments. It can be used to play simple tunes and also to illustrate some facts about stringed instruments.

   Make a long, shallow, wooden box like that shown in Fig. 45–3. Cut several large holes in the top, and glue triangular wedges near the two ends, as shown in the figure. String a wire over the box as shown, with weights hanging from one end. The instrument should be placed on the edge of the table so that the weights can hang freely. Piano wire is best to use, but any kind will do.

   The instrument may be tuned by adding or removing weights. It can be played with a violin bow or by plucking the string. Different pitches can be obtained by placing the finger at different points along the string and pushing down hard.

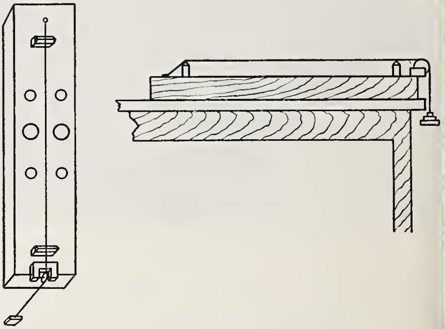
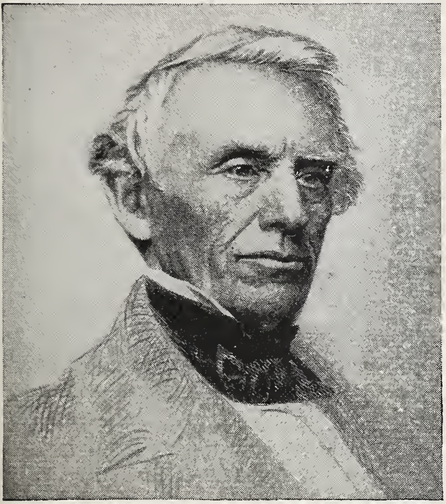


Fig. 45–3. A monochord.

Chapter 46

THE TELEGRAPH AND TELEPHONE

One of the wonders of our modern world is the ease with which men can communicate with one another even when separated by thousands of miles. A businessman in New York can lift his telephone, give a number, and, in a few minutes, talk to a business associate in London, Cairo, Melbourne, or any other part of the world having regular telephone service. This has not always been so. Only a little over a hundred years ago there were no telephones, telegraphs, or radios. As late as 1860 overland communication in the United States was still chiefly by the famous pony express. Then electricity made possible the telegraph, telephone, radio, and television.



Courtesy Western Union Telegraph Co.

Fig. 46–1. Samuel F. B. Morse (1791–1872), the inventor of the telegraph.

The Telegraph. The telegraph was invented by Samuel F. B. Morse in 1832. Morse first publicly demonstrated his invention by sending over a wire from Baltimore to Washington the now famous message "What hath God wrought!" This proved a fitting remark for the opening of our modern era of rapid communication. Morse's telegraph has changed little in a century, but it has been replaced almost entirely by the teletype.

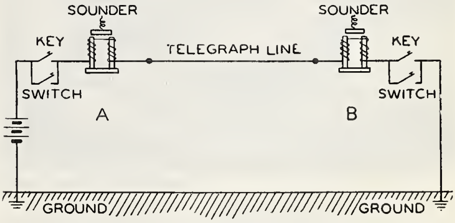


Fig. 46–2. A simple telegraph circuit.

A simple telegraph system includes a *key* and a *sounder*. The *key* is an electric switch which is normally kept open by a spring and is closed by pushing down on a large button. The key may be kept permanently closed by a switch handle. The *sounder* is a horseshoe electromagnet which, when an electric current passes through it, pulls down a soft iron armature against its poles, making an audible click When current stops flowing through the magnet, the armature is pulled upward by a spring until it hits a stop and gives out another click.

The circuit of a simple telegraph system is shown in Fig. 46–2. When the circuit is not in use the two keys are kept closed by their switches. During this time the current flows from the battery through the key and sounder at station A, along the wire, and through the sounder and key at station *B*, and back through the ground to the battery at A. When the operator at A wants to talk to the operator at *B*, he opens the switch on his key. He sends his message by dots and dashes made by pressing down and releasing his key. Dashes are made by holding the key down for a fraction of a second, and dots by holding it down for a shorter interval. Each letter in the alphabet is represented by a different combination of dots and dashes known as the *Morse code*. The sequence of clicks made by *A*'s key and sounder is repeated exactly by *B*'s sounder. When A has finished, he closes his switch and the operator *B* can send his reply.

Courtesy United Air Lines

Fig. 46–3. Teletype operators dispatching messages to points all over the country. This is part of a private teletype system operated by a large commercial air line.

The Teletype. Most long-distance communications, however, are now sent by teletype machines like those shown in Fig. 46–3. The teletype is operated in much the same way as a typewriter. The message is typed out on the keyboard, producing electrical impulses that operate a similar automatic typewriter at the receiving end. The teletype is more accurate than the telegraph. As the message is printed automatically, no operator is needed at the receiving end and Morse code is unnecessary.

The Telephone. The telephone was invented by Alexander Graham Bell in 1876. The basic parts of a telephone system are simple, and their operation is easy to understand. The two essential parts are a *microphone* and a *receiver*.

A diagram of an ordinary telephone *microphone* is shown in the upper part of Fig. 46–5. It consists of a small brass box, about an inch in diameter, that is filled with small particles, or granules, of carbon about the size and shape of coarse grains of sand. Attached to the cover of the box is a flexible diaphragm. When sound waves strike this diaphragm, it vibrates and causes the cover of the metal box to vibrate as well. The vibration of the cover is relayed to the carbon granules; they, in turn, offer varying resistance to the electric current flowing through them. When the carbon particles are compressed, their resistance to the electric current is reduced; when the pressure is released, they separate and their resistance is increased. The varying resistance causes a varying current in the line.

A telephone *receiver* is a small horseshoe electromagnet with a soft-iron diaphragm a fraction of an inch from the poles. When the varying current flows through the coils of the magnet, the diaphragm vibrates and reproduces the sound waves. Even complex sound waves that strike the diaphragm of the microphone are accurately reproduced in the receiver of a modern telephone. Fig. 46–5 shows a simple telephone circuit consisting of a microphone, receiver, battery, and connecting wires.

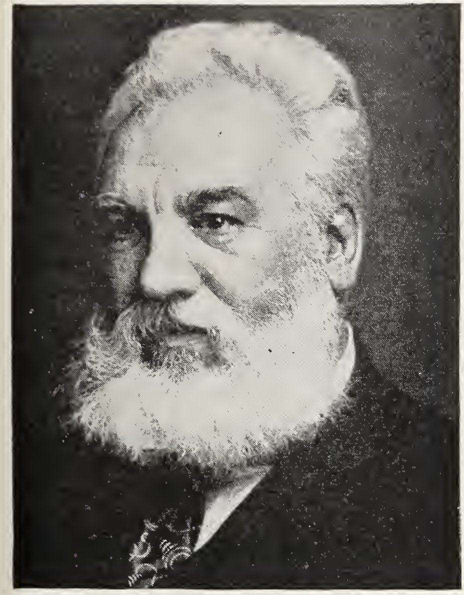

Courtesy American Telephone and Telegraph Co.

Fig. 46–4. Alexander Graham Bell (1847–1922), the inventor of the telephone.

Telephone Repeaters. If a simple telephone circuit is set up to cover a distance of many hundreds of miles, the resistance of the telephone lines is so great that the current flowing in the circuit is too weak to operate the receiver at the far end. This difficulty is overcome by the use of *repeaters* spaced about 30 miles apart along the line. By means of vacuum tubes the repeaters amplify, or step up, the voltage and current, so that there will be sufficient power to operate the receiving apparatus at the distant location. In order to understand how vacuum-tube amplifiers work, you must first learn something about vacuum tubes themselves.

VACUUM TUBES

A vacuum tube is an evacuated glass or metal tube enclosing several metal elements that control the flow of electrons through the vacuum. The simplest kind of vacuum tube is a *diode*, which is used to rectify alternating currents, that is, to change them to direct currents.

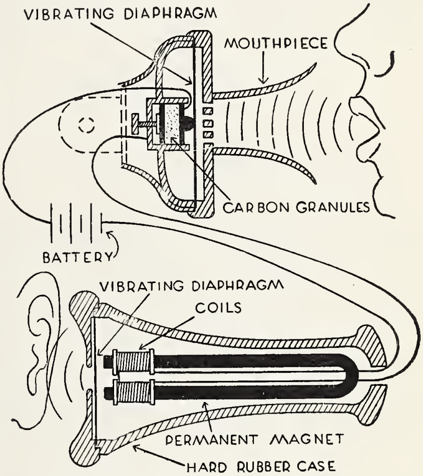


Fig. 46–5. A simple telephone circuit.

Diodes. The diode has two important elements, a *cathode* and a *plate*. The properties of a diode were discovered by Thomas Edison while he was developing his incandescent electric light. In addition to the filament he sealed an extra wire into a light bulb, and connected a battery and an ammeter between the filament and this extra wire as shown in Fig. 46–6. He found that a current flowed through the ammeter when the filament was lighted. If, however, the polarity of the battery was reversed, so that the extra wire (in modern diodes, called the *plate*) was negative, no current flowed through the ammeter.

The above effect has been called the *Edison effect.* Its explanation is quite simple. When the filament becomes hot, its atoms vibrate so rapidly that some electrons are knocked out of the atoms on the surface of the wire and, unimpeded by air molecules, fly out into the vacuum in the bulb. This process is similar to the evaporation of molecules from a liquid, because the higher the temperature of the filament, the greater is the number of electrons given off. If the plate has a positive charge, the electrons that leave the filament are attracted to it, and flow through the ammeter, back to the battery, *B*. Moreover, as fast as electrons leave the filament, or *cathode,* as it is commonly called, more electrons from the same battery take their place. However, if the plate is made negative by reversing the connections of the *B* battery, it repels the electrons from the filament and no current will flow. Notice that there are two circuits in Fig. 46–6, the *plate circuit* supplied with current by the *B* battery, and the *filament circuit* supplied with current by the *A* battery.

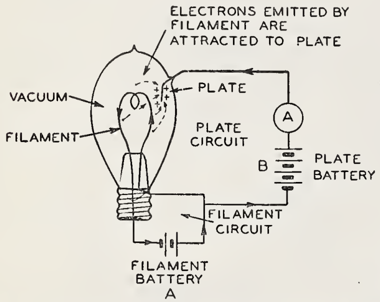


Fig. 46–6. The flow of electrons from the filament in this bulb to the plate wire is called the Edison effect.

The only function of the filament circuit is to heat the filament so that it will give off electrons. Such diodes (Fig. 46–7) are used in *electronic* apparatus.

Triodes. A *triode* tube, as its name suggests, has three important elements, and is used to amplify a current. Like a diode, it has a cathode and a plate; in addition it has a *grid* of fine parallel wires placed between the cathode and the plate. Lee DeForest, an American, was the first to make such a tube. He found that when the grid is charged negatively, the flow of current between cathode and plate is reduced, because electrons moving from the cathode toward the plate are repelled back toward the cathode by the negatively charged grid. As a result, only a few electrons get between the grid wires and reach the plate. If the grid is made positive, however, electrons are helped on their journey to the plate, and the current through the tube is increased.

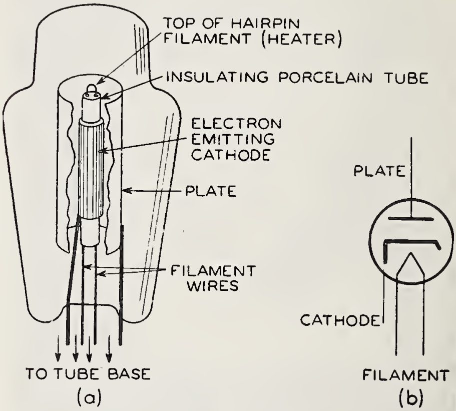

TOP OF HAIRPIN FILAMENT (HEATER)
INSULATING PORCELAIN TUBE
ELECTRON EMITTING CATHODE
PLATE
FILAMENT WIRES
TO TUBE BASE
(a)
PLATE
CATHODE
FILAMENT
(b)

Fig. 46–7. The construction of a simple diode and its schematic symbol is shown in (*a*). Some modern tubes have an indirectly heated cathode as shown in (*b*) in which the electron-emitting cathode is heated by a filament that is not electrically connected to the cathode.

Demonstration 46–1. The Construction of a Triode Tube.

Obtain a burned-out triode tube with a glass envelope (such as a 6J5G or 6J5GT) from a radio-service shop. After wrapping it in cloth, break the glass envelope by squeezing it in a vise. With a pair of wire cutters, remove the plate and examine the structure of the tube. Look carefully for the three elements—grid, cathode, and plate—and notice how they are connected to the prongs on the base of the tube.

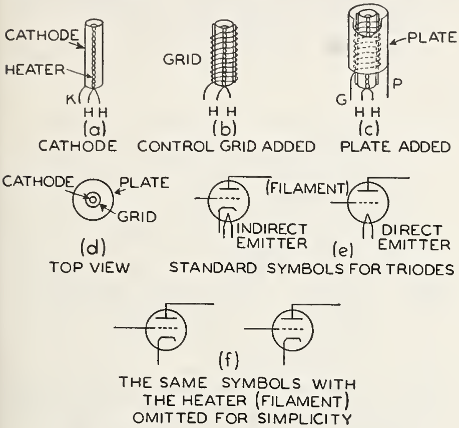


Fig. 46–8. Construction of a triode tube.

The grid, as DeForest discovered, can be used to control the current and voltage in the plate circuit and, most important of all, *a small change in the voltage applied to the grid of the tube will produce a very large change in voltage in the plate circuit of the tube.* It is this property of a triode that gives us our modern electronic amplifiers that change small voltages to large, useful voltages in telephone repeaters, phonographs, radios, sound-movie projectors, and many other devices.

By the use of such amplifiers it is possible to talk into a telephone in New York and be heard in San Francisco as clearly as though the telephone line were only a few feet long. But let us return to the businessman in New York who wishes to talk to someone in London. How can we amplify signals every thirty miles along a submarine cable lying on the floor of the Atlantic Ocean? This is not easy, and so we turn to radio waves. Today transoceanic telephoning is accomplished by means of radio links over the ocean from one shore to the other. In the next chapter you will learn about radio communication.

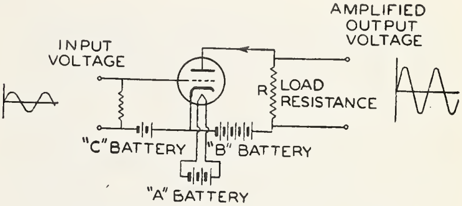


Fig. 46–9. A simple amplifier circuit.

THINGS TO REMEMBER

The *telegraph* was invented by Morse in 1832.

The *telephone* was invented by Bell in 1876.

A *diode* is the simplest kind of vacuum tube that contains a filament, cathode, and plate.

Diodes are used as *rectifiers* to change alternating current to direct current.

A *triode* contains filament, cathode, grid, and plate.

A triode can be used to *amplify* weak electric currents.

QUESTIONS

A

1. Who invented the telegraph, and when was it first used?

2. What are the essential parts of a telegraph?

3. How is a telegraph sounder constructed?

4. What is a teletype?

5. State the advantage of the teletype over the simple telegraph.

6. Who invented the telephone, and when?
7. What are the essential parts of a simple telephone circuit?
8. What are telephone repeaters, and where and why are they used?
9. What is a diode tube?
10. What is a triode, and for what can it be used?

B

11. Draw a diagram of a simple two-way telegraph circuit, and describe its operation.
12. Describe the construction and operation of a microphone.
13. Describe the construction and operation of a telephone receiver.
14. Draw the circuit of a simple one-way telephone system.
15. What is the Edison effect?
16. Why will no current flow through a diode when the plate is charged negatively and the cathode charged positively?
17. What is the function of the grid in a triode?

PROJECT

To Make a Simple Microphone. A simple homemade microphone is shown in the Fig. 46–10. The base is a cigar box in which two double-edged razor blades are imbedded. An electrical connection is made by soldering a wire to each blade and laying a pencil lead across the edges of the blades. The microphone should be connected in series with a telephone receiver and 3-volt battery of two dry cells connected in series. If an alarm clock is placed on the box, you will be able to hear it tick by listening in the receiver. Can you explain how this microphone works?

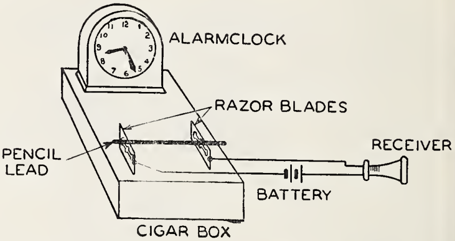


Fig. 46–10. A simple microphone can be made from a cigar box, two razor blades, and a pencil lead that will pick up the "ticks" of an alarm clock.

Chapter 47

RADIO AND ELECTRONICS

Radio is one of man's most spectacular inventions. By radio the complex sounds of a symphony can be sent through space to be reproduced at distant places by radio receivers. Radio waves—electromagnetic waves of wave length too great for the human eye to see—make this transmission possible. These waves, traveling at the speed of light, enable a radio listener in Boston to hear the words of a speaker in a large auditorium in New York before the people in the back rows of the hall hear them. This is because radio waves travel almost a million times as fast as sound. Similarly, television enables us, by means of radio waves, to see at a distance far beyond the range of the human eye. How has man learned to put electromagnetic waves to such amazing uses? To answer this question, let us go back a century to the time of James Clerk Maxwell, a Scottish mathematician and physicist.

The Discovery of Radio Waves. From his studies of light waves, Maxwell predicted that radio waves must exist and have properties similar to those of light waves. Heinrich Hertz, a German physicist, was the first scientist to demonstrate in the laboratory that such waves could be produced and detected by man. The apparatus he used to generate and detect these waves was very simple, consisting mainly of two spark gaps (see Fig. 47–1). The spark gap on the left was supplied with a high voltage so that a series of sparks jumped across the gap. The adjustable wire loop and gap on the right was placed a few feet away and, when the sliding connection on the loop was placed at the proper point, sparks would also jump across this gap though there was no source of power in this "receiver." The energy of the spark had traveled by electromagnetic waves through space from the "transmitter" to the receiver.

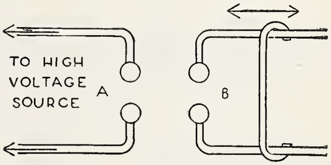


Fig. 47–1. Hertz's apparatus for generating and receiving radio waves.

Hertz investigated the properties of these waves and found, as Maxwell had predicted, that they could be reflected by metal surfaces, focused into beams, and refracted. Hertz never thought of the possibility of using these waves for communication purposes. It was Guglielmo Marconi, an Italian, who first put them to practical use in the form of wireless telegraphy.

Early Wireless Telegraphy. Marconi increased the distance over which radio waves could be sent, and used them for communication purposes. To do this he used higher voltages and consequently bigger sparks in the transmitter, coupled with long wires, or antennas, to better radiate the electromagnetic energy through space. He also used a more sensitive detector than Hertz's simple spark-gap receiver. Marconi started in 1893 by sending a message over a distance of 5,000 feet. In 1899 he communicated, by *wireless telegraphy*, as radio was then called, across the English Channel. In 1901 he succeeded in receiving at St. John's, Newfoundland, signals from a transmitter in England. This event marked the coming-of-age of radio. Soon ships were using Marconi's apparatus to keep in touch with their home ports and to appeal for help in emergencies. One of the first dramatic uses of wireless telegraphy resulted in the arrest of a man wanted for murder. It was suspected that the criminal was fleeing from England to Canada. This information was sent by wireless and the man was arrested as he stepped off the boat at Halifax.

Radio communication did not progress beyond simple wireless telegraphy for some time—not until the triode vacuum tube was perfected. In 1920 station KDKA in Pittsburgh broadcast the first radio entertainment program of voice and music.

Generation of Radio Waves. To understand how an electric spark produces radio waves we must first realize that a spark discharge consists, not of a simple flow of electric charges in one direction, but rather of a rapid vibration of charges across the spark gap. In other words, an alternating current flows across the gap. The frequency of such alternating currents ranges from a few thousand cycles to several billion cycles per second. Flowing in the wires of a transmitting antenna, these *high-frequency currents* send out electromagnetic waves in all directions through space with the speed of light.

Radio transmitters no longer use electric sparks to generate radio waves. Soon after the discovery of the Edison effect it was found that a triode vacuum tube would generate high-frequency currents much more efficiently. Modern radio transmitters contain many vacuum tubes connected in a complex circuit. They always contain an *oscillator tube* that generates alternating currents of specific frequency but usually of very low power. These alternating currents are then amplified many hundreds or thousands of times by a series of amplifier tubes and fed into the transmitting antenna, which radiates this energy as powerful radio waves to all corners of the earth. The arrangement of oscillator, amplifiers, and antenna is shown in Fig. 47–2.

A radio transmitter of this kind can be used only for radio telegraphy. The source of high-voltage power to the final amplifier tubes is turned on and off by means of a telegraph key, thus producing a radio wave interrupted according to the dots and dashes of the international Morse code. In order to transmit voice and music, additional equipment is needed, as described later in this chapter.

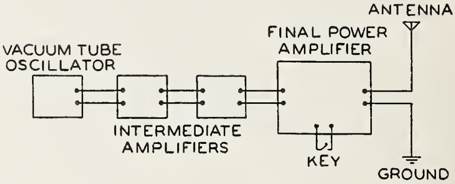


Fig. 47–2. Block diagram of a radiotelegraph transmitter.

Radio Static. Though radio waves produced by sparks are no longer of much practical use, we still have evidence of them in the form of *static*. The crashes of static heard on a radio during a thunderstorm are the result of radio waves produced by sparks of lightning. These waves travel with the speed of light. You can easily prove this by watching the sky for lightning while listening to the radio. The flash of lightning and the crash of static on the radio occur at the same instant; whereas the thunder, which travels at the slower speed of sound, is usually heard several seconds later. Vacuum cleaners, doorbells, electric shavers—in fact all electric devices that produce sparks—generate radio waves that interfere with normal radio reception.

Broadcasting Voice and Music (Radiotelephony). To transmit voice and music the high-frequency waves must be made to vary in intensity according to the variation in the sound waves of the voice or music. This is done by first converting the sound variations into a varying electric current by means of a microphone, just as in a simple telephone. This varying voice current, or *audio-frequency current,* is then amplified by a vacuum tube called a *modulator.* This amplified current controls the power applied to the final amplifier of a radio transmitter such as that shown in Fig. 47–3. In this way the intensity of the radio waves is varied in accordance with the sound variations of the voice or music entering the microphone. This type of *modulation* (varying of the radio waves in accordance with the sound to be broadcast) is called *amplitude modulation* because the amplitude, or intensity, of the waves is varied. *Frequency modulation,* which has some advantages over amplitude modulation, is discussed later in this chapter.

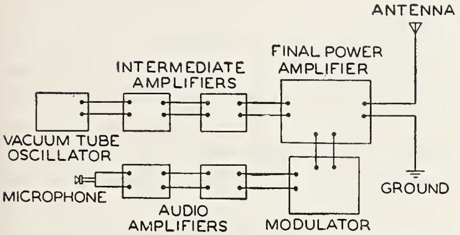


Fig. 47–3. Block diagram of a plate-modulated radiotelephone transmitter.

Let us now summarize, with the aid of Fig. 47–4, the operation of a modern broadcast transmitter. Radio-frequency currents are generated by the oscillator tube. (These currents are shown in part *a* of Fig. 47–4.) They are amplified by intermediate amplifiers (see *b* and *c*), and still more by the final power amplifier, and then fed into the antenna. At the same time the microphone current (see *d* of Fig. 47–4) is amplified by the modulator *e,* and then used to vary the intensity of the radio-frequency currents in the final amplifier, as shown in *f.* Thus we have a high-frequency current that varies in intensity at a much lower audio rate, and a corresponding radio wave is radiated from the antenna.

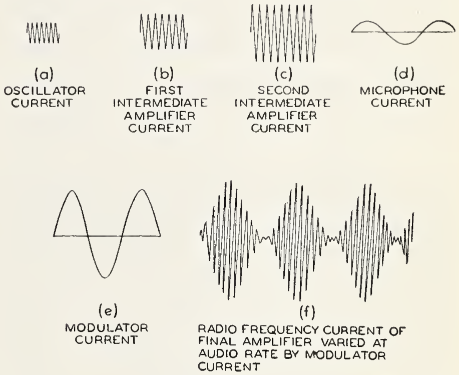

(a)
OSCILLATOR CURRENT
(b)
FIRST INTERMEDIATE AMPLIFIER CURRENT
(c)
SECOND INTERMEDIATE AMPLIFIER CURRENT
(d)
MICROPHONE CURRENT
(e)
MODULATOR CURRENT
(f)
RADIO FREQUENCY CURRENT OF FINAL AMPLIFIER VARIED AT AUDIO RATE BY MODULATOR CURRENT

Fig. 47–4. Wave forms in different stages of a plate-modulated radiotelephone transmitter.

A Simple Radio Receiver. Let us now examine a simple radio receiver to see how radio waves may be picked up, detected, and converted into audible sound. Four parts are needed: (1) an antenna, (2) a tuned circuit, (3) a detector, and (4) a reproducer. The antenna need be only a wire, between 30 and 100 feet long, insulated from surrounding objects and placed high above the ground. One end of it runs to the tuned circuit, which consists of a coil and a *con-*

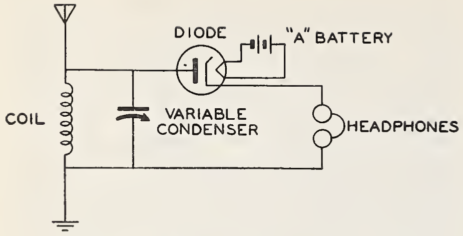


Fig. 47–5. A simple radio-receiver circuit.

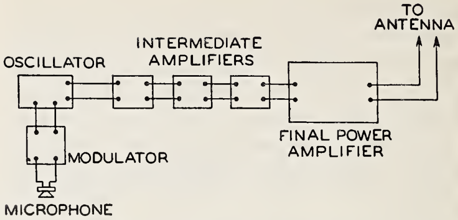


Fig. 47–7. A simplified block diagram of a frequency-modulated transmitter.

denser (see Fig. 47–5). The tuned circuit is connected to the diode detector which, in turn, is connected to the reproducer. The reproducer consists of a pair of headphones and is similar to a telephone receiver. Fig. 47–5 shows how this apparatus is connected.

Modern Radio Receivers. The simple receiver we have already discussed could have its *sensitivity,* or ability to pick up weak signals, increased by additional vacuum tubes. *Audio amplifiers* can be added to increase the power of the signal from the detector. *Radio-frequency amplifiers* can be placed between the antenna and detector to amplify the radio-frequency currents from the antenna before they are detected. A receiver using both these kinds of amplification is called a *tuned radio-frequency receiver.* Most modern receivers are essentially of this type but include an additional tube, a converter, in what is called a superheterodyne circuit.

Frequency Modulation. Recently another method of transmitting and receiving radio signals has come into use. It is known as *frequency modulation.* A frequency-modulation (FM) transmitter is similar to an amplitude-modulation (AM) transmitter except that a very low-power modulator is used to vary the frequency of the radio-frequency currents generated by the oscillator tube. Fig. 47–7 is a diagram of such a transmitter. The radio wave from the antenna is constant in intensity but varies in frequency according to the sounds picked up by microphone. Fig. 47–8 shows an amplitude-modulated wave and a frequency-modulated wave. Notice how the

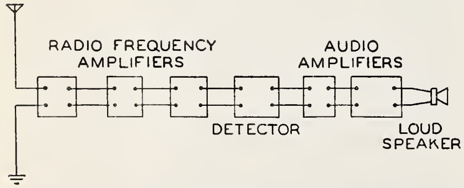


Fig. 47–6. A tuned radio-frequency receiver. Each radio-frequency amplifier stage contains a tuned circuit.

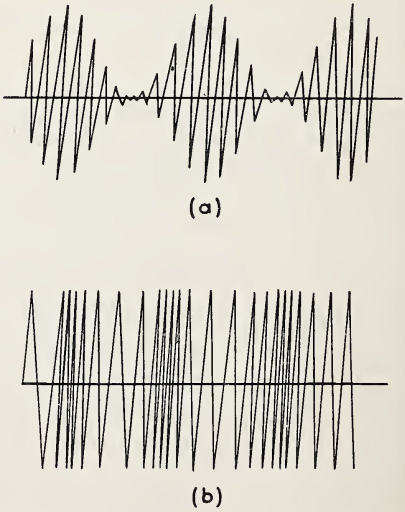


Fig. 47–8. *(a)* Amplitude-modulated waves; *(b)* frequency-modulated waves.

length of the frequency-modulated wave is constantly changing. This means, of course, a constantly changing frequency. The intensity of the frequency-modulated wave, on the other hand, remains the same. This is the exact opposite to an amplitude-modulated wave, in which it is the intensity that is continually changing while the frequency remains constant.

A frequency-modulation receiver is essentially the same as an amplitude-modulation receiver except that it contains a different type of detector, called a *discriminator*. The discriminator is a diode, but it is arranged in a circuit that will convert changes in frequency to changes in strength of a direct current. This direct current, changing at an audio rate, is then amplified in the usual way and fed into the loud-speaker. Both AM and FM receivers are sometimes built into one set so that either type of broadcast may be received.

The principal advantage of FM over AM is that much less static is picked up by an FM receiver. This is because most static consists of amplitude-modulated waves and has very little frequency modulation.

Transmission of Radio Waves over Long Distances. Using light waves, we can see only as far as the horizon. One might well ask why radio waves, which have properties similar to light waves, can bend around the curvature of the earth and travel all over the world. They can do this because far above the stratosphere there is a layer of air at very low pressure called the *ionosphere* (see Fig. 19–19 in Chapter 19). The ionosphere conducts electricity; and though it cannot reflect light, it does reflect the longer electromagnetic waves of radio around the curved surface of the earth. Actually, not much radio energy is reflected by the ionosphere from stations in the standard-broadcast band. Most of the energy from these stations reaches us directly through the atmosphere and through the earth's surface. The reflection of the ionosphere is most efficient in the short-wave band, and stations operating in this range are used for transoceanic telephone service.

Since there are many thousands of radio transmitters now operating all over the world, the lower frequencies are overcrowded. Therefore such new developments as FM and television (TV) must operate on the very high frequencies where there is more room. Since the range of transmitters operating on these frequencies is only as far as the natural horizon (such high-frequency waves not being reflected by the ionosphere), FM and television transmitting antennas are usually placed as high as possible, on the tops of tall buildings and hills, to extend their range. For the same reason FM and television receiving antennas should also be placed as high above the ground as possible.

Television. Television—the transmission of light images by means of an electric current and radio waves—is accomplished by taking apart the picture to be transmitted and sending it piece by piece by high-frequency radio waves to the receiver, where it is put together again. The whole process is so rapid that the eye is conscious only of the completed moving picture.

The scene to be televised forms an optical real image on a special sensitive surface in the television pick-up tube located in the studio. The image is formed by a system of lenses in a camera that is similar to an ordinary photographic camera; the sensitive surface in the pick-up tube corresponds to the film of an ordinary camera. A narrow beam of electrons from a hot cathode in the pick-up tube scans the sensitive surface back and forth, line by line, moving down the surface until it has covered the whole surface in a manner similar to that in which one reads a page in a book. As the beam sweeps over the light and dark areas of the real image, a varying electric current is produced that modulates a radio transmitter. This, in turn, produces a varying current in the output of a television receiver that controls the intensity of a beam of electrons in the picture tube of the television receiver. This beam is made, by complex electronic circuits, to scan the face of the picture tube exactly in step with the beam of electrons in the pick-up tube in the television studio. It thus produces a pattern of light and dark on the picture-tube face that is an exact reproduction of the scene being televised. The image of the televised scene is scanned in about $\frac{1}{30}$ second—so fast that the eye is unaware of the scanning process and sees a steady, continuous picture. The process of transmission and reception is shown in Fig. 47–9.

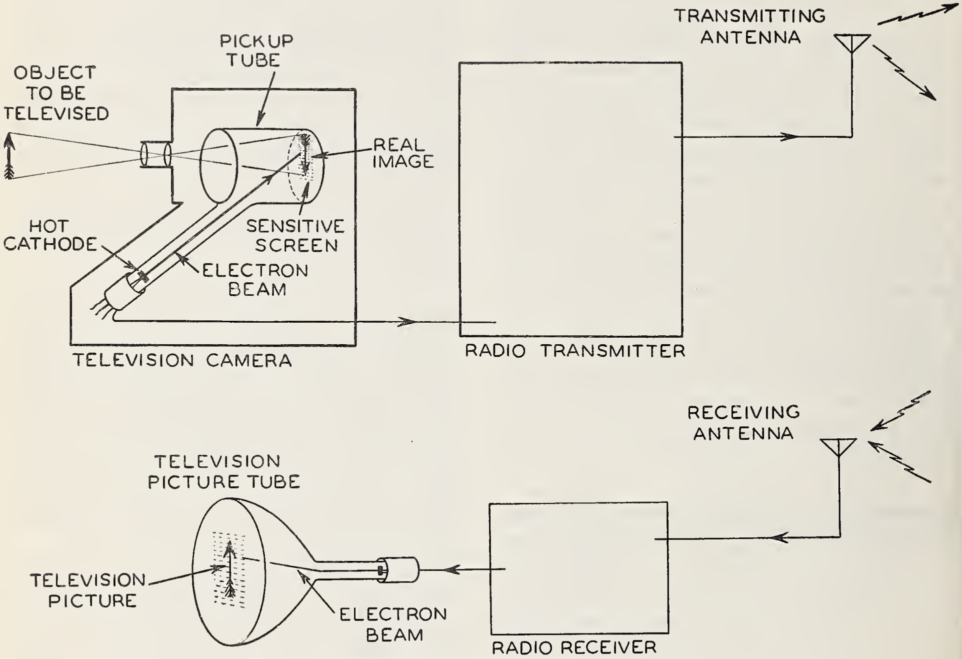


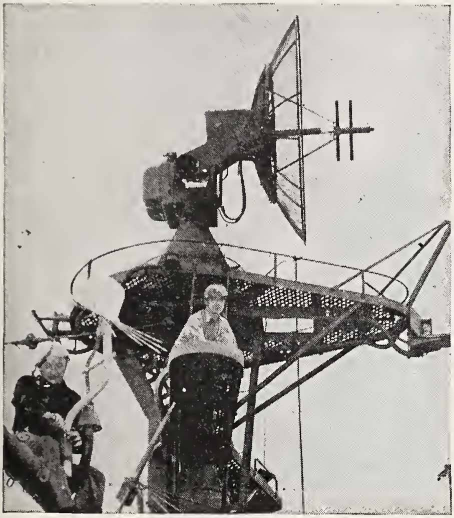
Fig. 47–9. Television transmission and reception.

Color television is produced in the same way as black-and-white television, except that the three colors red, blue, and green are transmitted and received separately and then combined in the final picture.

Radar. Radar (an abbreviation for *ra*dio *d*irection finding *a*nd *r*anging) is a device that employs radio waves of extremely high frequencies to locate objects through dense fog and clouds either in daylight or in darkness.

Every radar station employs both a transmitter and a receiver. The transmitter sends out a series of short pulses of radio waves focused into a narrow beam. These radio-wave pulses travel at the speed of light to the target and are reflected back by it to the antenna and into the receiver, as shown in Fig. 47–11. The target is first located by slowly scanning the horizon or the sky with the radio beam until a reflected signal is picked up on the receiver. The direction in which the beam is pointing shows the direction of the target. The distance of the target is found by measuring the time it takes a pulse to reach the target and return.

The apparatus needed for radar is complex and expensive. Radar proved its great usefulness during World War II in detecting through fog and clouds enemy airplanes and ships more than a hundred miles away. It is useful also in peacetime in navigating ships and planes through fog and clouds, because shorelines, buoys, icebergs, other ships and planes, and objects on the ground are easily identified. Since the very-high-frequency radio waves of radar are reflected by raindrops and snow, radar serves as a means of locating storms and observing their progress.



Courtesy General Electric Co.

Fig. 47–10. A large radar antenna on the top of the mast of the USS *Juneau*.

Some radar sets have been built to aim anti-aircraft and naval guns automatically. In World War II Japanese ships were destroyed with the aid of radar without having been seen by the ships that sank them.

One of the most complex types of radar used shows on a screen a complete map of the surrounding countryside. The remarkable radar picture shown in Fig. 47–12 is a photograph of a radar screen on a B-17 bomber flying over New York City.

Sonar. Radar is unable to "see" objects underwater, since water reflects radio waves. However, *sonar* (*so*und *n*avigation *a*nd *r*anging) was used during World War II to locate submerged submarines. In sonar, sound-wave pulses of a frequency just above the audible range are sent through the water and are reflected and received in the same manner as in radar.

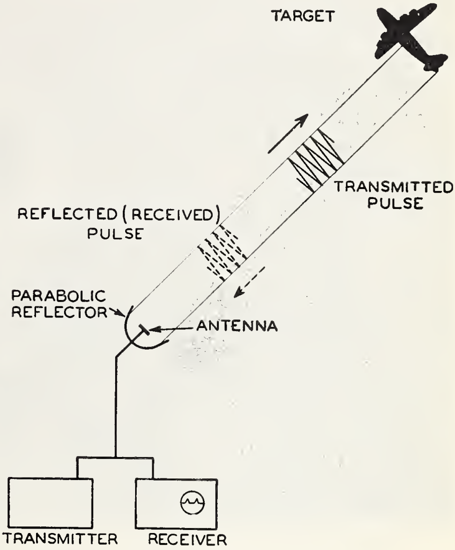
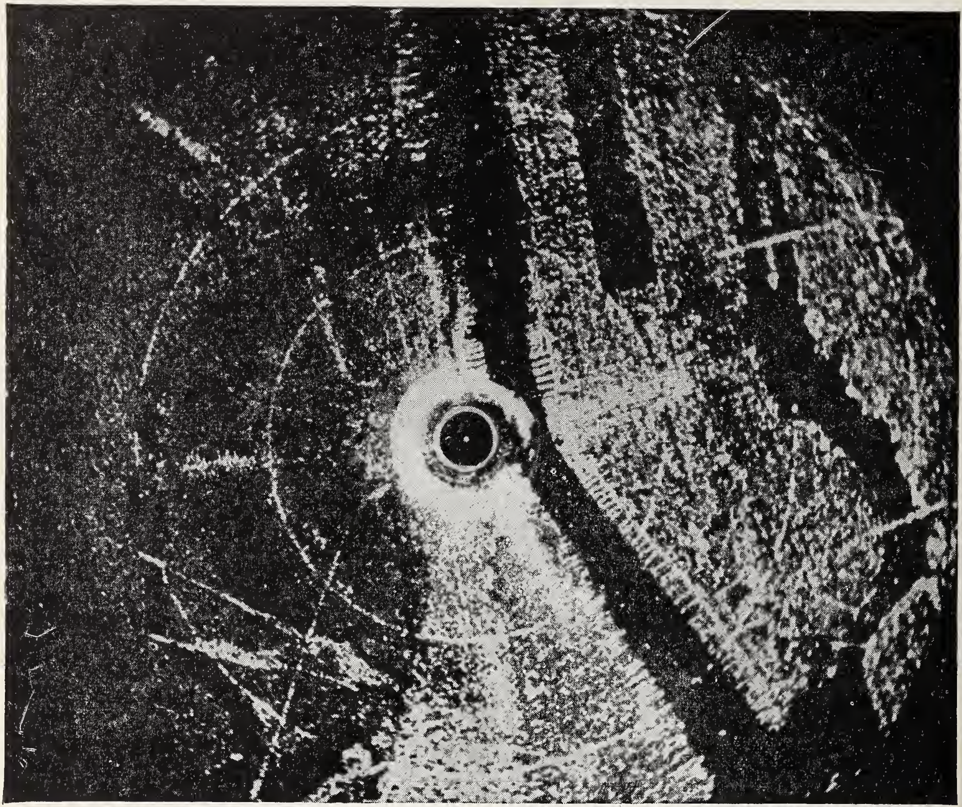


Fig. 47–11. A radar set receives reflected radio signals from the target it has located.

Loran. Loran (*lo*ng-*ra*nge *n*avigation) is a system now widely used by ships and planes for determining their positions at sea. Like radar, it employs short pulses of radio waves. These pulses are transmitted by shore stations and picked up on a loran receiver by a ship or plane. The actual position of the ship is



Courtesy Radiation Laboratory, Massachusetts Institute of Technology

Fig. 47—12. Radarscope photograph of part of New York City and northeastern New Jersey taken from a B-17. When the photograph was taken, the plane was almost directly over Union City, New Jersey (the spot in the center of the circle). Manhattan Island with Central Park in the northern section and the docks along the river, the Hudson River, the East River, and the Queensboro and Williamsburg bridges joining Manhattan and Long Island are all clearly visible in the right half of the photograph. In the left half, the crowded industrial centers of northeastern New Jersey and the winding course of the Hackensack River can easily be identified. Distance is indicated by the concentric circles used for navigation and bombing.

determined by measuring the length of time between pulses from a pair of loran stations transmitting simultaneous pulses. Actually data from two pairs of such stations are needed. In this way, it is possible to determine one's position accurately at distances of several thousand miles from the nearest loran station.

Other Uses of Radio. Radio waves have been put to hundreds of uses, including *blind-landing systems* by which a plane is made to land safely without the aid of a pilot; the familiar *radio range* or *radio beam* that keeps planes on their course; and unattended *automatic weather stations* that transmit complete weather reports at regular intervals from remote islands. There are also guided missiles that contain a television eye, enabling an operator on the ground to fly and control the missile straight to its target. In 1947 a plane took off from the United States, crossed the Atlantic, and landed safely in England without the pilot or anyone on the plane touching a single control except a switch to start the flight.

THINGS TO REMEMBER

Wireless telegraphy was invented by Guglielmo Marconi.

Voice and music programs were first broadcast in 1920.

Radio waves are electromagnetic waves produced by radio-frequency currents flowing in an antenna.

Vacuum tubes are used to generate and amplify radio-frequency currents.

In amplitude modulation the radio waves are varied in intensity according to the sound variation to be broadcast.

In frequency modulation the frequency of the radio waves is varied according to the sound variation to be broadcast.

Modern radio receivers include an *antenna*, a *tuned circuit*, a *detector*, *amplifiers*, and a *reproducer*.

Radio waves can travel long distances when they are reflected around the curve of the earth by the *ionosphere*.

QUESTIONS

A

1. Who first generated and detected radio waves?

2. How were radio waves first generated?

3. How are radio waves generated in modern transmitters?

4. What is the purpose of radio transmitting antennas?

5. What are the four essential parts of a radio receiver?

6. What is the reason for using amplifiers in a radio receiver?

7. What purpose is served by the antenna of a receiver?

8. How are radio waves able to travel around the curved surface of the earth?

9. Why are FM transmitting antennas often built on the tops of mountains?

B

10. How is amplitude modulation accomplished?

11. How is frequency modulation accomplished?

12. Draw a diagram of: (*a*) an amplitude-modulated wave; (*b*) a frequency-modulated wave.

13. What is the difference between an audio amplifier and radio-frequency amplifier?

14. Draw a block diagram of an amplitude-modulated transmitter.

15. Why are stations from all over the world heard by a short-wave receiver but not by an FM receiver?

PROJECTS

1. *To Build a Crystal Radio Receiver.* Obtain from a radio-service shop a coil, variable condenser, .01 microfarad fixed condenser, a 1N21 or similar crystal, and a pair of headphones. The coil and variable condenser from a worn-out radio will serve the purpose. Connect the apparatus as shown in the Fig. 47–13. The antenna should be as long as possible and can be made of any kind of wire, insulated or uninsulated. Since most variable condensers used in radios today are made of two or three separate condensers constructed as a single unit, be sure to use only one section of the condenser. The service man in the radio-service shop will probably give you advice and answer your questions about connecting the apparatus. This set will be sensitive enough to pick up powerful local stations.

   If you are interested in building an amplifier for your set or in making a better detector, write to the American Radio Relay League, West Hartford, Connecticut, for information or consult some of the books listed in the bibliography at the end of this unit.

2. *Visiting a Radio Station.* Try to organize a group to visit a local radio station. Arrangements for the trip can be made by telephone with the engineer in charge of the station. You will probably be provided with a guide. Look for the following things, preferably in the order mentioned:
   - (*a*) studio and microphone
   - (*b*) control desk
   - (*c*) radio transmitter
   - (*d*) transmission line for carrying radio-frequency currents to the antenna
   - (*e*) the antenna

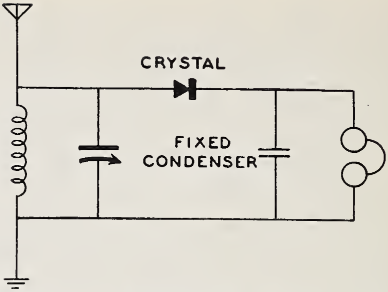


Fig. 47–13. A simple crystal receiver circuit.

REVIEW QUESTIONS ON UNIT 9

A

1. Draw a diagram of a diode tube.

2. Draw a diagram of a triode.

3. What is necessary to generate a sound and conduct it to the ear?

4. Determine which of the following statements are true and which are false. Then correctly reword the false ones.
   - (*a*) Transatlantic telephone service is accomplished entirely by the use of underwater cables.
   - (*b*) Telephone repeaters are used to record telephone messages in offices.
   - (*c*) A radio antenna is used to radiate and intercept electromagnetic waves.
   - (*d*) The telephone was invented by Samuel F. B. Morse.
   - (*e*) The telegraph was invented by an Italian named Marconi.
   - (*f*) The ionosphere reflects radio waves.

5. Complete each of the following statements by supplying the correct word or phrase.
   - (*a*) Sound waves travel at a speed of—?—.
   - (*b*) The difference between the tone of a clarinet and that of a trumpet is due to their different —?—.
   - (*c*) Every radio transmitter has a —?— to generate —?— currents.
   - (*d*) A radio-frequency amplifier amplifies —?— currents.
   - (*e*) Sound waves cannot travel through —?—.

6. Explain why radio signals can be transmitted around the curved surface of the earth to any part of the world.

7. What is contained in the spiral canal of the ear that aids the process of hearing?

8. What are radio waves, and how can they be generated?

9. What is a resonant column?

10. How does an organ pipe generate sound, and what determines the frequency of the sound generated?

11. A violin string vibrates at a frequency of 2,200 vibrations per second. What is the wave length of the sound it generates?

B

12. Describe the early experiments in which Hertz first produced and detected radio waves.

13. Draw a block diagram of a simple radio receiver and explain how it picks up radio waves and converts them into sound.

14. Distinguish between amplitude modulation and frequency modulation.

15. Determine which of the following statements are true and which are false. Then correctly reword the false ones.
   - (*a*) Frequency-modulation broadcast stations operate on very high frequencies.
   - (*b*) Sound waves are carried over wires in a telephone circuit.
   - (*c*) The common telephone microphone contains an electromagnet.
   - (*d*) A telegraph sounder contains an electromagnet.
   - (*e*) Diodes are used as amplifiers.
   - (*f*) A modulator is used to generate radio-frequency currents.

16. Draw a labeled block diagram of an amplitude-modulated broadcast transmitter.

17. (*a*) A resonant closed tube reinforces a sound whose frequency is 1,000 cycles per second. What is the length of the tube?

(*b*) What would be the length of an open tube?

18. Draw the circuit of a simple two-way telegraph circuit.

19. What is the range of audible frequencies?

20. What is meant by the amplitude of a sound?

21. Can two sounds have the same frequency and different amplitudes? Explain and give examples to support your answer.

SUGGESTIONS FOR FURTHER READING

A

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Unit 10

STRUCTURAL MATERIALS

48. IRON, AN IMPORTANT METAL
49. STEEL, A MATERIAL FOR CONSTRUCTION
50. COPPER AND ZINC
51. ALUMINUM AND MAGNESIUM
52. GLASS AND CEMENT

Chapter 48

IRON, AN IMPORTANT METAL

In earlier chapters we discussed machines, such as locomotives, ships, airplanes, and generators, which are essential to our modern world. We shall now consider the materials used in the construction of these machines, and give some thought to the important question: Are there ample supplies of these raw materials to meet our future needs?

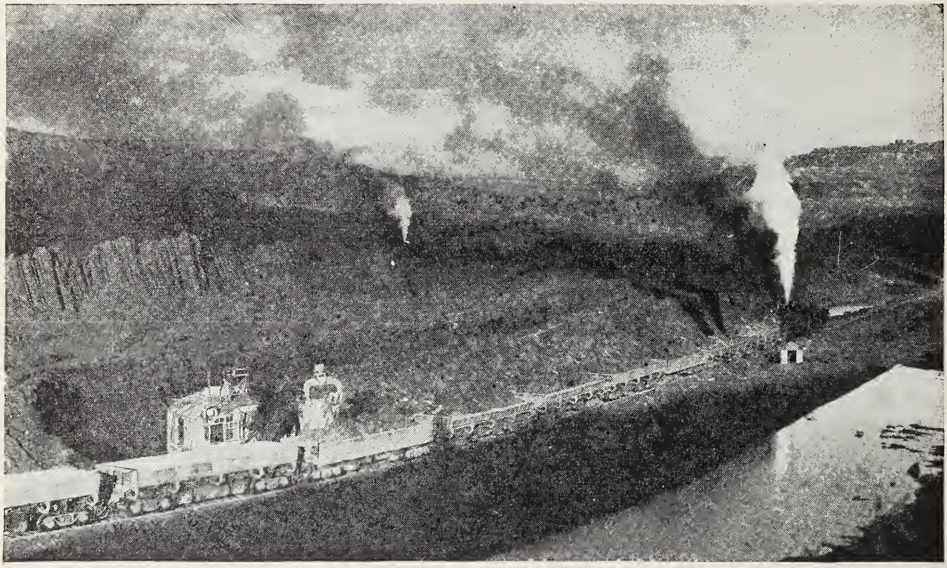
Machines, for the most part, are made of metals. Locomotives, for example, are made of steel and airplanes of magnesium and aluminum. Metals do not occur free in nature. They are usually present in the minerals and rocks of the earth as oxides, sulfides or carbonates.

A mineral that is rich in metal is called an *ore*. Before the metal can be used, it must be released from the mineral. This is done usually by chemical processes at very high temperatures. If the ore contains only a small amount of metal, a great deal of rock material must be discarded without loss of the valuable metal. Copper ore, for example, usually contains only 4 or 5 percent copper, and therefore the extraction of copper is a difficult operation. Whether or not it is profitable to mine a particular ore depends on the value of the metal obtained. For example, if the iron-bearing mineral *hematite* yields 50 percent iron, it is profitable to mine it. On the other hand, if a mineral yielded as little as 0.001 percent gold, it, too, would be worth mining because of the high value of gold.

Formation of Ore Deposits. Most rocks contain metals in the form of compounds. Usually, however, the amounts of metal are so small that it would be too expensive to extract them. Fortunately, in nature there is considerable concentration of metals. The geologist explores regions where such natural concentrations exist, and the chemist finds methods of refining the ores further.

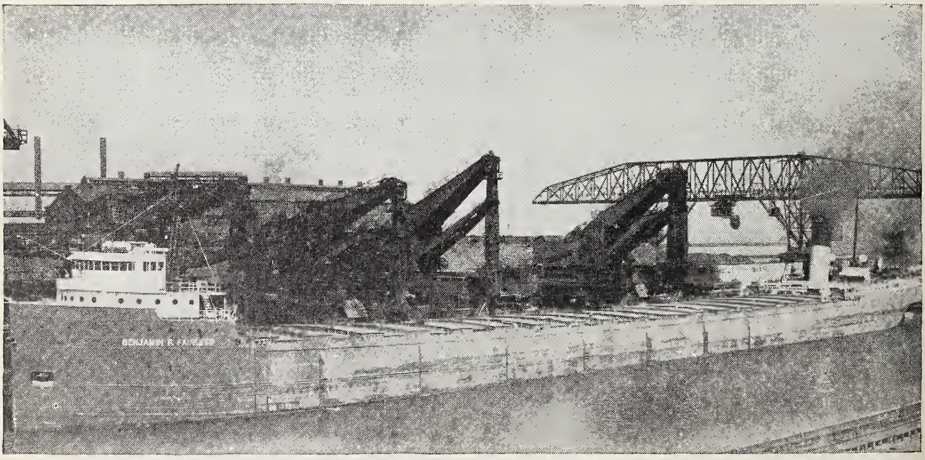
How did these minerals become concentrated into rich ore deposits? Originally minerals were in hot, molten igneous rock. Some of them dissolved in the superheated steam and were carried away as the steam escaped through the cracks in the rocks above. When the steam reached cooler regions, it condensed and the minerals were deposited in the cracks. It is believed that many ore deposits were formed in this way.

How were iron-ore deposits formed? Geologists believe that over long periods of time several different processes had a part in producing high-grade ore. The ore probably escaped from the molten rock either as a gas or in solution by the process described above. As the gas cooled, the ore was deposited *within* the earth as a sediment. Such a deposit of iron-bearing strata would form a low-grade ore, that is, an ore containing only about 25 percent iron. After the strata have been exposed to weathering and erosion, the more soluble rock particles are dissolved and carried away, leaving behind the less soluble



Courtesy United States Steel Corp.

Fig. 48–1. The Hull-Rust iron-ore mine located at Hibbing, Minnesota. This open-pit covers 1,300 acres and contains 55 miles of railroad tracks.



Courtesy United States Steel Corp.

Fig. 48–2. An ore carrier being unloaded at the docks.

iron minerals. Thus the proportion of iron is increased to form a high-grade ore containing from 50 to 60 percent iron.

Iron-Ore Deposits in Canada. Canada is the eighth iron-ore producing country in the world. At present 65 percent of our production comes from the Steep Rock and Michipicoten districts on Lake Superior, and the balance from the Wabana mines in Newfoundland. Iron-ore deposits are also found in British Columbia, Alberta, New Brunswick, Nova Scotia and the Yukon Territories, but these are overshadowed by the discovery of very large deposits in the Labrador-Quebec district.

The known ore reserves in this area are now 417 million tons, and further exploration will undoubtedly raise this estimate. Production is planned at ten million tons a year which will give the field a minimum life of forty years. The importance of these deposits is emphasized by the fact that the supply of high-grade ore in the United States will be exhausted in little more than twenty years.

Mining of Iron-Ore. When ore deposits occur close to the surface of the earth *open-pit* mining is possible, and ore is extracted more cheaply than in *underground mining*. The open pits are worked in terraces, because excavation and transportation are more efficient when these operations are performed on a number of levels. The brownish-red ore is scooped up with giant shovels and loaded on railroad cars, as shown in Fig. 48–1. The mines in Ontario and the new Labrador-Quebec mines are open-pit, but the Wabana mines are underground, actually extending under the sea.

Ore from the mines is broken up and carried by rail to loading docks. Newfoundland ore is brought by freighter to the blast furnaces at Sydney, Nova Scotia. The Ontario mines supply Sault Ste. Marie, Hamilton, and Montreal as well as sending ore to the American steel centers at Cleveland, Detroit, Buffalo, and Pittsburgh. Ore from the Labrador-Quebec mines will be brought 300 miles by rail to huge loading docks at the Town of Seven Islands on the St. Lawrence. Freighters will then carry it up the river to the cities mentioned above.

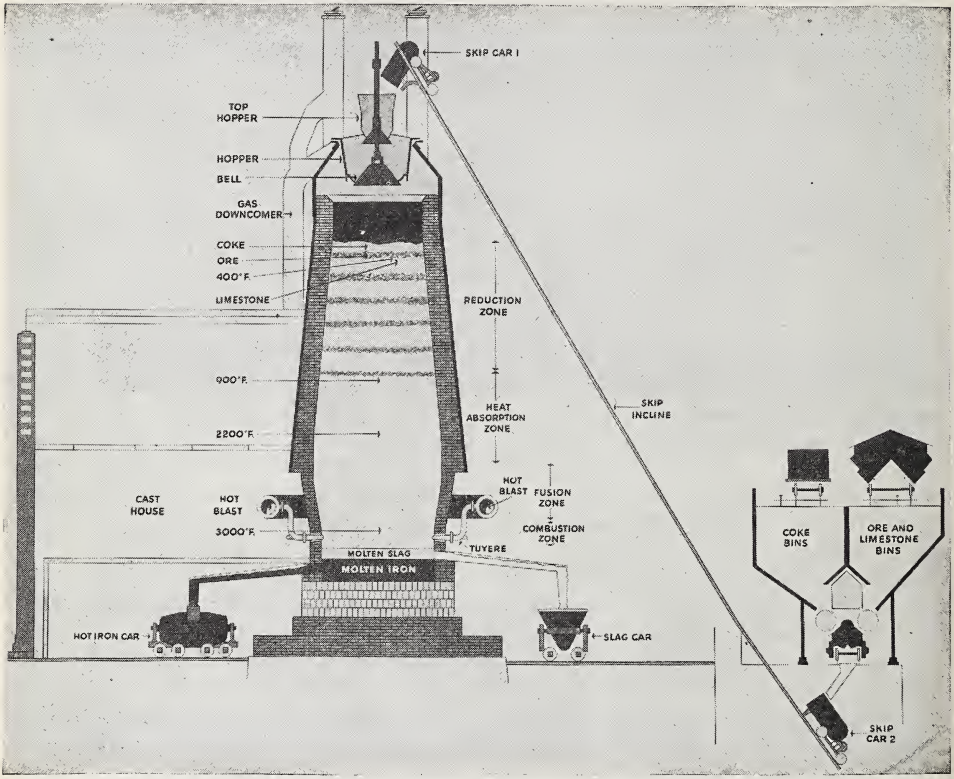
Iron in Earlier Times. The extraction of iron from ore was known to the Egyptians and Syrians as early as 1500 B.C. These peoples heated a mixture of iron ore and charcoal, but because they were unable to produce temperatures high enough to melt the iron, they obtained iron as a spongy, pasty mass. This iron contained a great deal of *slag* (impurities) that had to be beaten out of the hot iron by hammering. The purer iron was used for swords, knives, armor, and chariots; the inferior grades for axes and plowshares.

Many iron tools, such as axes, saws, and nails are mentioned in the Old Testament. One interesting reference (1 Chron. 22:3) describes David's plans for building a temple about 1000 B.C.: "And David prepared iron in abundance for the nails for the doors of the gates, and for the joinings."

In England the iron industry grew rapidly during the 15th and 16th centuries, and many forges and furnaces were built. The charcoal used to extract iron from its ore came from timber. So much wood was used for this purpose that there was a shortage of timber for shipbuilding. As a result a law was passed during Queen Elizabeth's reign making it illegal to cut trees for making iron except in certain areas. In the 17th century coal was substituted for charcoal. But coal gave off heavy smoke and oil vapors. In the 18th century, to avoid this disadvantage, coke was substituted for coal. This step marked the beginning of the modern method of manufacturing iron.

The first ironworks in the United States were built in Virginia about 1620. Thirty or forty years later the colonists began to make iron on a large scale. They poured the molten iron into molds to make such household utensils as pots and pans. By the middle of the

18th century there were numerous iron furnaces and forges, particularly in Pennsylvania. During the Revolutionary War many of the forges made cannons and cannon balls for the Revolutionary forces. The British therefore destroyed many forges, such as Valley Forge, for example. Did you know that George Washington's father was at one time an ironmaster?

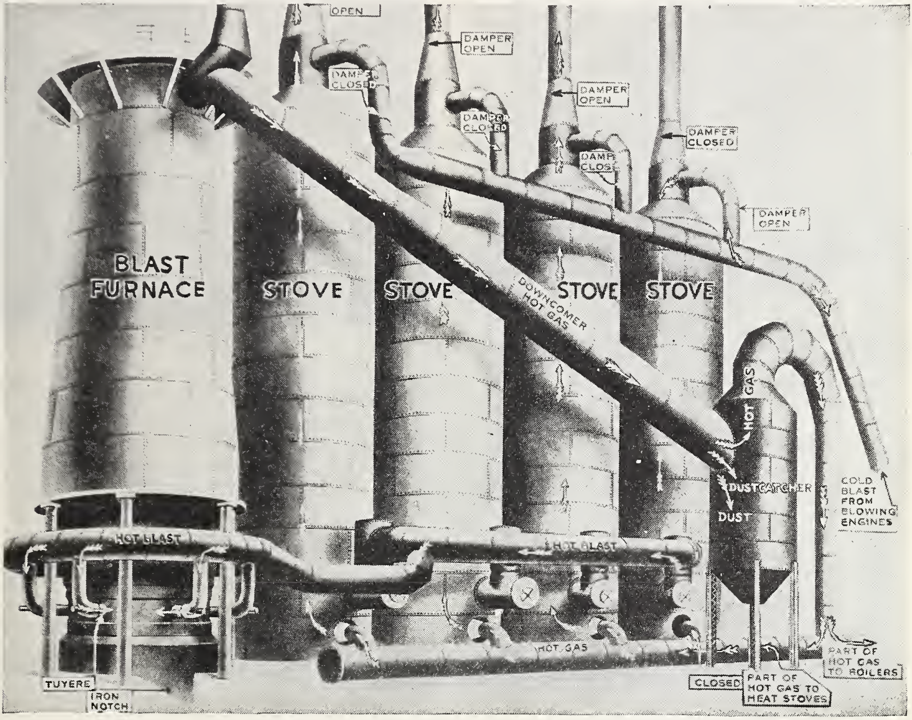


Courtesy of Bethlehem Steel Co.

Fig. 48–3. A section of a blast furnace.

The Blast Furnace. Blast furnaces are used to make iron—the first step in the manufacture of steel. The blast furnace is a huge steel tower, about 100 feet high and 20 feet wide, lined with firebrick, a material that can withstand the great heat of the furnace. Near the bottom of the furnace are openings to admit hot compressed air, and near the top is a pipe to carry away the exhaust gases. Iron ore, coke, and limestone are poured continuously into the top of the furnace, and the molten iron and slag collect at the bottom. The slag floats on the iron but does not mix with it. The molten slag is drawn off from time to time and hauled away. Rock wool, an insulating material, is made by blowing high-pressure steam through the molten slag. Slag is also used in making concrete.

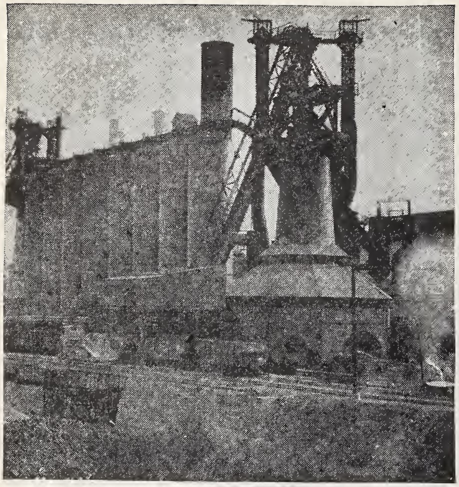
Cast Iron or Pig Iron. The iron obtained from a blast furnace contains about 4 percent carbon and smaller amounts of other impurities, such as sulfur, phosphorus, and manganese. This high percentage of carbon makes the iron too brittle for structural work where great strength is required. The molten metal can be poured or cast in molds. It is then called *cast iron*. Some cast iron is used in automobile parts, such as cylinder blocks, flywheels, and water-pump cases. Most of it, however, is used in the manufacture of steel.



Courtesy American Steel and Wire Co.

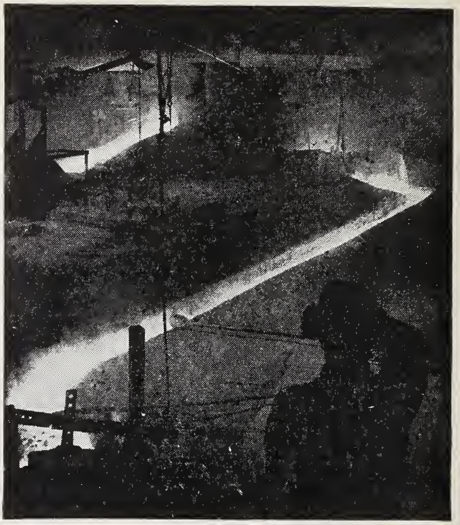
Fig. 48–4. There are usually four stoves, filled with firebrick, to each furnace. Blast furnace gas is burned in three of the stoves, while cold air is forced through the fourth stove. Every two or three hours the stoves are "changed"; that is, the cold air is switched to a hot stove and the cooled stove is heated up. In this way hot fresh air is supplied continuously to the furnace.

Cast iron is sometimes called *pig iron*. The origin of the term is interesting. In the old days the molten iron was cast into a main trough from which smaller troughs led off at right angles. Here the iron solidified into bars that were sold to manufacturers. Some imaginative person thought that the troughs resembled a sow and her suckling pigs. For this reason the castings were called *pigs* and the iron was called pig iron, and this name is still used.



Courtesy United States Steel Corp.

Fig. 48–5. This picture shows two blast furnaces and eight stoves. The furnace at the right is running off molten slag into ladles at the lower right.



Courtesy United States Steel Corp.

Fig. 48–6. This picture shows the release of molten iron and slag. Slag is released from the upper tapping hole on the left and flows into the ladle. Molten iron is released through the lower tapping hole on the right and is guided through a runner to the ladle on the lower left.

THINGS TO REMEMBER

An *ore* is a metallic mineral that is rich enough in metal to make its mining profitable.

A *low-grade* iron ore contains about 25 percent iron; a *high-grade* iron ore contains about 50 percent iron.

Ontario mines produce about 65 percent of Canada's iron ore.

Iron ore is *converted* into pig iron or cast iron in the blast furnace.

Pig iron is used chiefly in the manufacture of steel.

QUESTIONS

A

1. What is: (*a*) an ore; (*b*) hematite; (*c*) slag?

2. Write briefly on: (*a*) the Labrador-Quebec deposits; (*b*) iron ore deposits in Canada; (*c*) the transportation of ore.

3. State the difference between a low-grade and a high-grade iron ore.

4. Explain briefly how the early Egyptians made iron.

5. How is rock wool made and what is it used for?

6. (*a*) What is pig iron?
(*b*) What are some of its uses?

B

7. Explain how high-grade iron ore is formed.

8. Describe a blast furnace and explain how it operates.

PROJECT

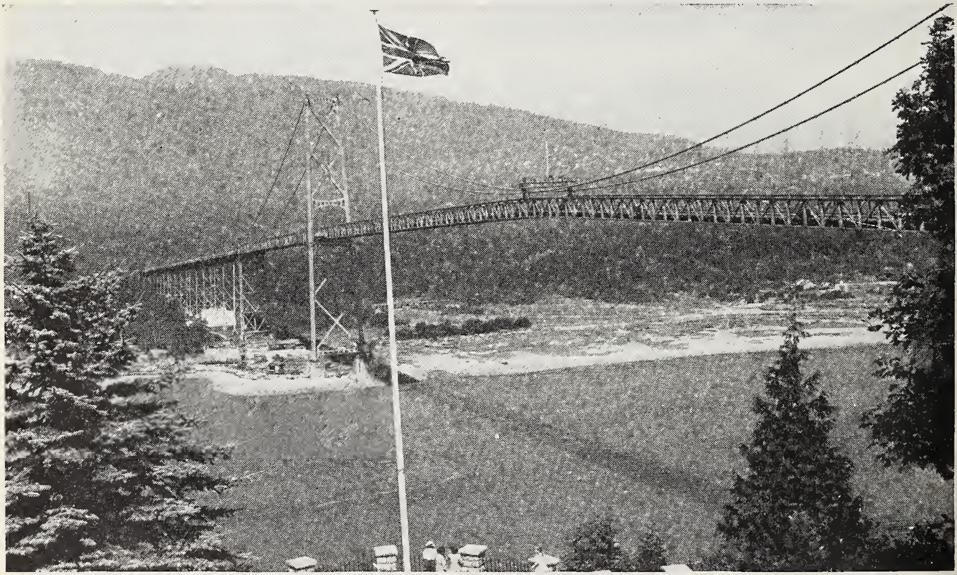
Reporting on the Labrador-Quebec Iron Ore Deposits. Prepare a report on the discovery, present development, and future potentialities of the iron ore deposits in the Labrador-Quebec region north of Seven Islands. Include a discussion of the reasons for the importance of this discovery and the difficulties that must be faced in getting the mines into production. Draw a map indicating the principal consuming centers for the ore when it is available and the possible routes that may be used to transport the ore to them. Explain how the proposed St. Lawrence Seaway, when it is built, will facilitate the movement of the ore to the blast furnaces and list some of the other advantages that this seaway will bring.

For aid in this project, you can get information and literature by writing to the Department of Mines and Technical Surveys in Ottawa, the Iron Ore Company of Canada, the Labrador Mining and Exploration Company, Ltd., or the Hollinger North Shore Exploration Company, Ltd. There have also been several articles in various magazines, such as the Canadian Geographic Journal and the C.I.L. Oval (published by the Public Relations Department, Canadian Industries, Ltd., Montreal).

Chapter 49

STEEL, A MATERIAL FOR CONSTRUCTION

More than 90 percent of the metal used in the world is steel. Steel is used in shipbuilding; in the manufacture of automobiles, locomotives, derricks, pipelines, generators, transmission-line towers, and railroad tracks; in making cutlery, tin cans, and many other articles. The automobile industry in the United States uses more than 20 per cent of the steel produced each year—more than that used by any other industry. The average American home contains hundreds of pounds of steel in various forms.



Courtesy British Columbia Government

Fig. 49-1. Lions Gate Bridge—a steel bridge, 1,500 feet long, connecting the City of Vancouver with West Vancouver.

The United States produces more steel than all other countries combined. About 100,000,000 tons of steel are produced annually, and more than 400,000 men are employed in the steel industry.

Pittsburgh produces more steel than any

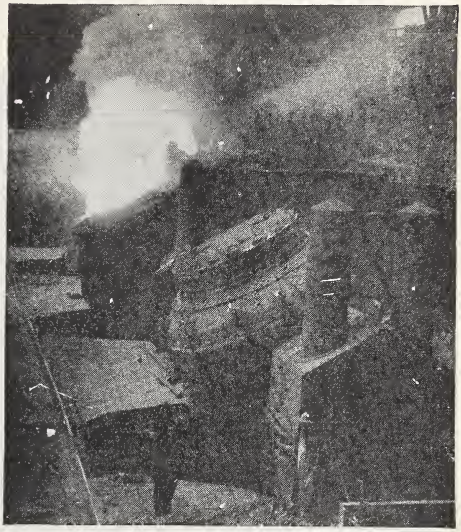
other city. If you look at a map of the United States, you will see that Pittsburgh is more than 800 miles from the Minnesota iron deposits and 150 miles from Lake Erie. Why, then, is it the steel capital? Pittsburgh is near the large coal sections of Pennsylvania and West Virginia. In the early days of the steel industry it was cheaper to ship iron to coal than coal to iron. At Pittsburgh the Allegheny and Monongahela rivers flow together and form the Ohio River, making Pittsburgh one of the largest river ports in the world.

Composition of Steel. Steel, one of the strongest of all materials, is a product consisting of iron and a small percentage of carbon and some other metals; that is, it is an alloy of iron. There are many different kinds of steel. They differ from one another in the percentage of carbon and other ingredients present and also in the ways in which they are cooled, or tempered. Usually, the greater the amount of carbon, the harder is the steel. Hardness is not always desired; sometimes a softer steel is needed so that it can be welded or bent.

About a hundred years ago Henry Bessemer, an Englishman, discovered a new method of manufacturing steel. Before Bessemer's time guns were made from brittle cast iron and were therefore easily broken. Bessemer believed that stronger guns could be made if some of the carbon were removed. He melted pig iron in a crucible and blew air through the molten metal. The oxygen in the air burned out most of the carbon, leaving a steel that was much stronger than the pig iron. This simple experiment became the basis of the first method of large-scale steel manufacture. A great deal of steel is still made by the Bessemer process.

The Bessemer Process. The Bessemer converter is a pear-shaped steel vessel about 10 feet high. It is mounted so that it can be tilted first to receive molten pig iron and later to pour off the molten steel. It is lined with material such as limestone that does not melt at the high temperatures reached in the operation.

From 15 to 25 tons of molten pig iron are poured into the converter. A strong blast of air is sent through small holes at the bottom of the converter. The oxygen in the air burns out the impurities. The burning causes brilliant flames to shoot from the mouth of the furnace, which at night can be seen for miles. When the slag is removed, an almost pure iron is left in the converter. The correct amounts of carbon, manganese, and other ingredients are then added to make the desired kind of steel.

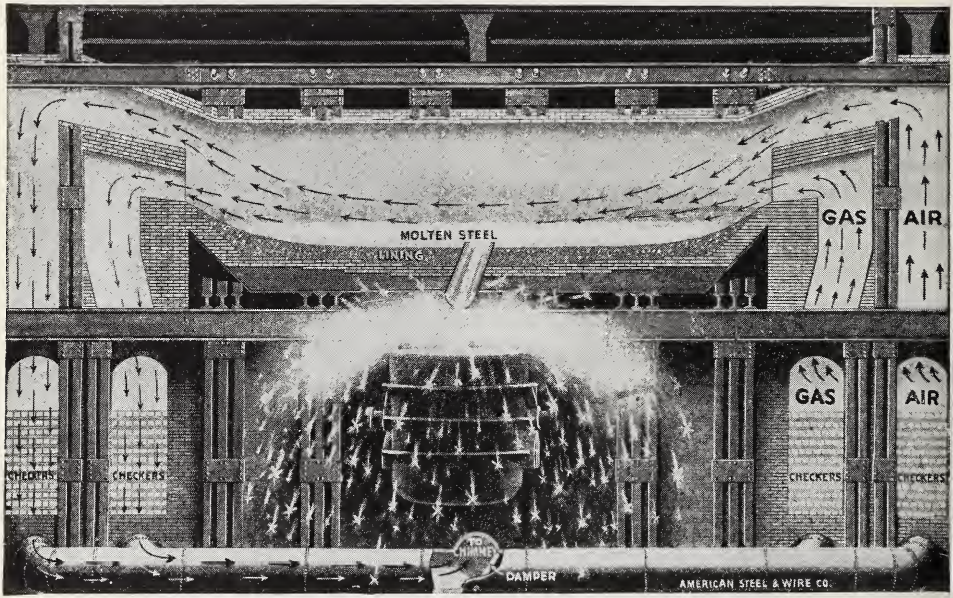


Courtesy United States Steel Corp.

Fig. 49–2. A Bessemer converter in action.

The Bessemer process is rapid, but the exact composition of the steel made by it cannot be controlled. In the open-hearth process, which we shall now discuss, the composition of the steel can be controlled during the operation.

The Open-Hearth Process. About 90 percent of the steel made in the United States is produced by the *open-hearth process*. This method is less expensive than the Bessemer process because scrap steel as well as pig iron can be used. In fact, about one-half of the charge is scrap, such as waste pieces from steel mills, worn-out machinery, old boilers, bridges, ships, and other structures.



Courtesy American Steel and Wire Co.

Fig. 49–3. Open-hearth process. Molten steel, about 24 inches deep, is heated by the flames from hot air and gas. The hot exhaust gases pass out through the checkers at the left and thence to the chimney. The damper at the bottom is then turned over to the left, thereby reversing the current and heating the checkers on the right.

The furnace is a bowl-shaped steel container with a roof that reflects the flames back on the charge. The charge consists of molten iron from the blast furnace, scrap steel, and iron ore. The iron ore in the charge supplies oxygen to oxidize the impurities and burn out the carbon. Heat for the process may be obtained by burning fuel gas. The shallow hearth holds a pool of liquid metal about three feet deep and weighing from 100 to 150 tons.

High temperature keeps the metal molten. Samples of molten steel can then be taken out and analyzed. Various ingredients, such as manganese and nickel, are added until the steel has the desired composition.

Rolling Steel. Molten steel is poured into hollow molds to form *ingots*, or large oblong blocks. These hot ingots are run between two rollers to stretch the steel. The steel is then run through other rollers which shape it for industrial uses. Forms as different as railroad rails and thin plates for use in the construction of automobile bodies are made by rollers.

Tempering Steel. Steelmaking is one of the oldest trades. The strong and flexible Damascus swords were made by the Syrians more than two thousand years ago. The steel in these swords contained a good deal of carbon, which usually makes steel hard and brittle. But these ancient sword-makers discovered that steel could be made flexible by heating and hammering it. A flexible steel is one that gives slightly but recovers its shape when the stress is removed. The early Romans defeated the Celts mainly because of their superior swords and other steel weapons. The Celts did not know how to make steel flexible and strong; their swords were so soft that they had to be straightened after every blow.

The process of heating and then cooling a metal is known as *tempering*. In the tempering of steel, the rate of cooling is the main factor. Hot steel is cooled quickly when placed in water or more slowly when immersed in oil or compressed air. The rate of cooling affects the crystalline structure of the steel, and this determines its hardness, strength, and flexibility. A manufacturer therefore can decide what kind of steel he wants and then temper it in the way that will give the desired properties.

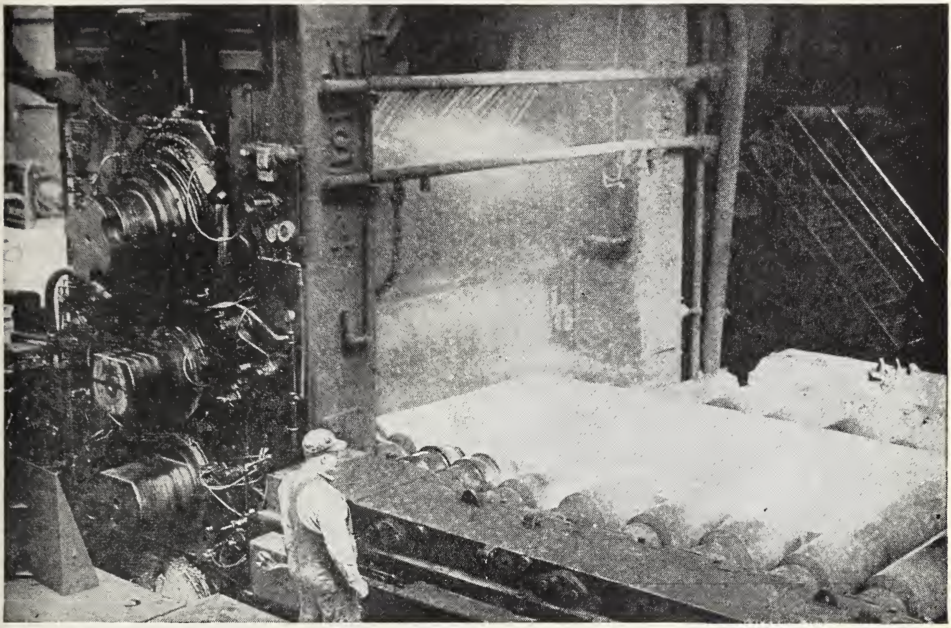

Courtesy United States Steel Corp.

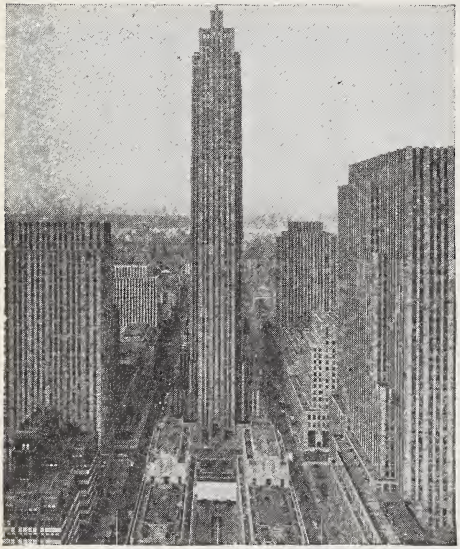
Fig. 49–4. Rolling ship plates. This white-hot slab is being reduced to a plate about an inch thick.

ALLOY STEELS

Manganese, tungsten, molybdenum, vanadium, chromium, nickel, and other metals are often added to steel to increase its strength or to give it other desirable qualities. If you look at thin slices of an alloy under a microscope, you will see the tiny crystals of these metals scattered in the steel.

Manganese Steel. Manganese is added to most steels to harden them. Steel that contains about 10 percent manganese is so hard that it cannot be cut or drilled. Manganese steel is manufactured into such articles as steam-shovel buckets, burglarproof safes, and machinery used for crushing. The best manganese ore in the United States is found in Montana, but it is not a high-grade ore.

Tungsten Steel. Tungsten is a hard, strong metal which, when added in the right amount, gives special properties to steel. Because tungsten steel keeps its strength and hardness even when very hot, it is used in making machine tools. Although these tools cut metals so fast that their edges become red-hot, they remain sharp and are able to keep on cutting. If machine tools were made of ordinary steel, they would lose their edge when hot and would have to be cooled frequently. Without these high-speed steels the mass production of automobiles would not be possible. There is not enough tungsten in the United States to meet our needs. We therefore import some from Bolivia, Peru, and China.



Courtesy Rockefeller Center, Inc.

Fig. 49–5. Rockefeller Center in New York consists of fifteen buildings. In its construction about 130,000 tons of steel were used.

Molybdenum Steel. Molybdenum is a hard, silvery white metal that makes steel tough, and it can be used in place of tungsten in making high-speed steel. Fortunately for the United States, about 90 percent of the world's molybdenum is in Colorado.

Vanadium Steel. Vanadium is the hardest of the metals; it adds strength and toughness to steel. Vanadium steel is used in making automobile axles, gears, crankshafts, and locomotive piston rods. There is plenty of vanadium ore in the United States, but some vanadium is imported from Peru.

Chrome Steels. If steel is 12 percent chromium, it will not rust or corrode. It is therefore called *stainless* steel. Stainless steels also contain manganese, silicon, and usually nickel. They are used for high-grade cutlery. Because they are not affected by acids or intense heat, they are suitable materials for furnaces, oil refineries, and chemical plants.

If chrome steel is 6½ percent or more nickel, it has great strength and toughness. Chromium-nickel steels are made into armor plate for battleships and tanks.

There is not much nickel or chromium in the United States. Nickel is imported from Canada, where more than 80 percent of the world's supply is found. Chromium ore, called *chromite*, is imported from South Africa, New Caledonia, Cuba, and Turkey.

Tin Cans. Tin cans are made almost entirely of thin sheet steel—not tin. The steel is merely coated with a thin layer of tin to protect it against the action of the acids in fruits or vegetables. The layer is usually so thin that tin constitutes only about one percent of the weight of the can. Tin cans were invented by an Englishman more than a hundred years ago. He called his invention a "tin canister." In England the name has been shortened to "tin," in America to "can."

THINGS TO REMEMBER

Steel contains much less carbon than pig iron and is much stronger than pig iron.

The *Bessemer process* is the rapid method of making steel from pig iron. The impurities in the iron are burned out by a blast of air.

The *open-hearth process* of making steel is less expensive than the Bessemer process; both pig iron and scrap steel are used in the charge.

Hot steel ingots are rolled into various shapes by passing the steel repeatedly between rollers.

Tempering determines the hardness, strength, and flexibility of steel. It is caused by the rate of cooling of hot steel.

Small quantities of certain metals are used for manufacturing *steel alloys* that have special properties. *Manganese* steel is hard and tough. *Vanadium* steel is very strong. *Tungsten* steel and *molybdenum* steel are used for high-speed tools. Stainless steel is *chrome-nickel* steel; it is tough, acid-resistant, and stainless.

QUESTIONS

A

1. Write briefly on (*a*) Henry Bessemer; (*b*) Damascus swords.

2. Why did Pittsburgh become an important steel center?

3. (*a*) What is an alloy steel? (*b*) Name four alloy steels.

4. State the countries where ores of the following metals are found: (*a*) tungsten; (*b*) nickel.

B

5. Briefly describe the Bessemer process for making steel.

6. What are the advantages and the disadvantages of the open-hearth process as compared with the Bessemer process?

7. Describe the properties and uses of: (*a*) tungsten steel; (*b*) molybdenum steel.

8. (*a*) What is meant by tempering steel? (*b*) Why is steel tempered?

9. (*a*) What are chrome steels? (*b*) What is their composition? (*c*) For what are they used?

PROJECTS

1. *Reporting on the Uses of Steel.* Make as complete a list as you can of the uses of steel in your home, your school, and your town.
2. *Making an Ore Collection.* There are many kinds of ores in the United States; ores of iron, copper, lead, zinc, and silver are not hard to find. An ore collection can fill out your rock collection if you have started one.

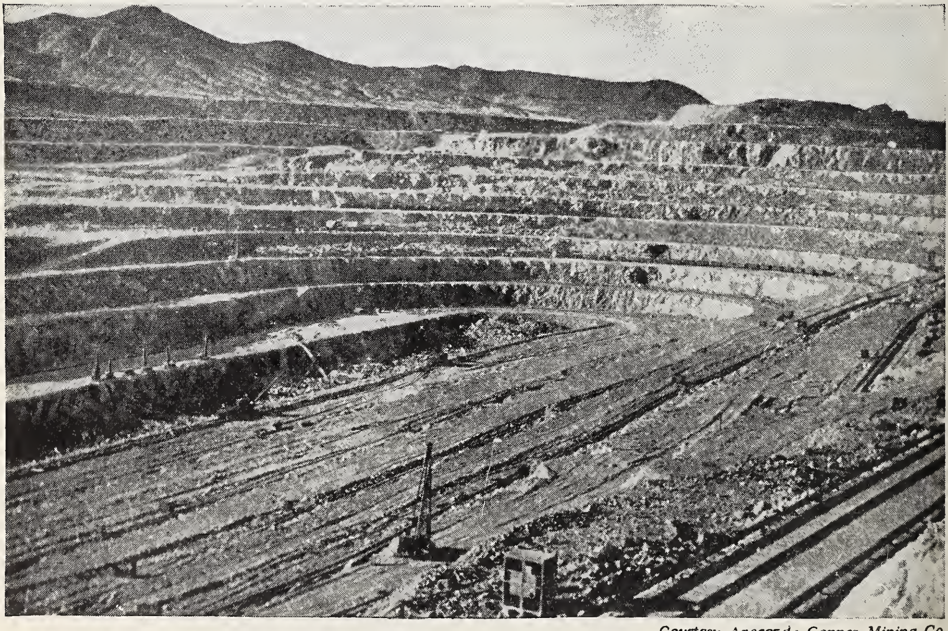
Chapter 50

COPPER AND ZINC

Copper and zinc are metals that do not rust. They are frequently found in the same region, as in the Butte district in Montana. This area of about five square miles is an igneous domelike mound from which vast quantities of copper, lead, zinc, manganese, silver, and gold have been obtained. It is called "the richest hill on earth, a mile high and a mile deep."

COPPER

There are rich copper deposits in Canada. It is found in six provinces, but Ontario is the principal producer, accounting for 44 percent of total Canadian production. Copper ores have different colors: *malachite* is green, *cuprite* is red, and *chalcocite* and *copper pyrite* are multicolored.



Courtesy Anaconda Copper Mining Co.

Fig. 50–1. An open-pit copper mine in Chile. The mine is worked on terraces. The picture shows railroad cars for loading the ore on at least three of the terraces.

Some of the deepest Canadian copper mines extend more than a mile below the surface of the earth. Vertical shafts are sunk, and from the shafts cuts are made at different levels to the ore veins. The shafts are used for hoisting the ore, men, and equipment, as in coal mining.

The Extraction of Copper from Its Ore. Metallic copper is obtained from the ore in five operations—concentration of the ore, roasting, smelting, oxidation, and refining. Let us see why the extraction of copper is so much more complicated than that of iron. For one thing, copper ore usually contains many more impurities than iron ore, and it is nearly always a low-grade ore, containing only about 5 percent copper. The ore must therefore first be concentrated.

Courtesy Anaconda Copper Mining Co.

Fig. 50–2. Drilling holes before dynamiting in a copper mine in the Butte district.

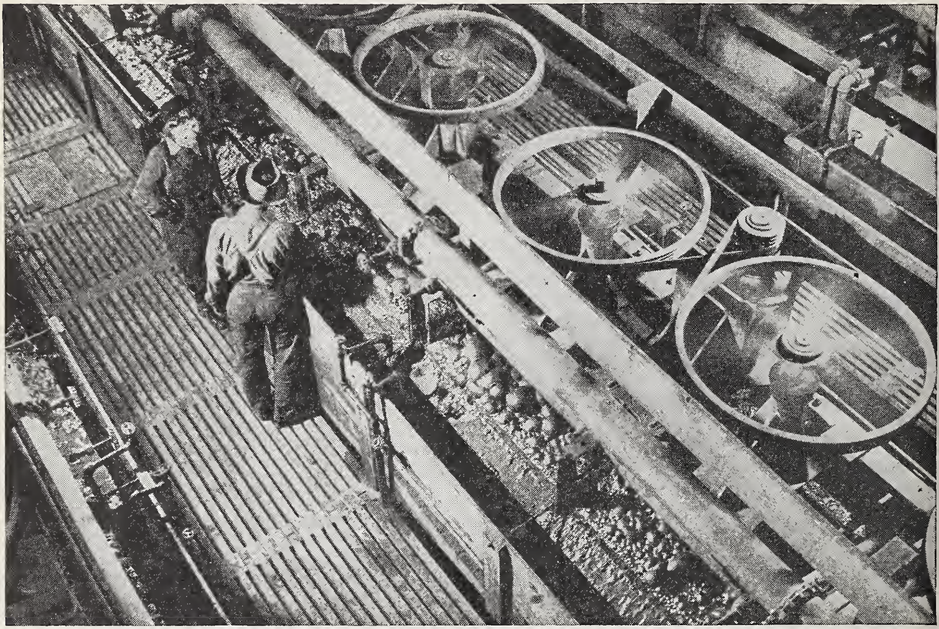
Concentration of the Ore by Oil Flotation. Copper ore contains a great deal of waste rock, most of which is eliminated by an oil-flotation process. The ore is ground to a fine powder and then mixed with water. Small amounts of oil and certain chemicals are added, and the mixture is agitated by compressed air. The chemicals cling to the copper ore, and the oil bubbles formed during the agitation carry this mixture to the surface, where it is skimmed off. The rock particles remain below the surface of the liquid and are later removed as waste.

In this way the copper, originally about 5 percent of the ore, is increased to 25 or 30 percent of the concentrate, but the chemical composition of the ore is not changed. In the next process the ore is further concentrated by fire-refining methods in which chemical changes take place. The first step in fire refining is roasting.

Roasting. The most common ores of copper are sulfide ores. They contain, in addition to copper, such substances as sulfur, iron, alumina (aluminum oxide), silica, silver, and gold, all of which must be removed. The object of roasting the ore is to remove the excess sulfur.

The concentrate is placed on the hearth of a furnace, and heated and scraped to expose all the ore to the air. Since it is finely ground, a reaction readily takes place. Only the iron sulfide in the ore reacts with the oxygen of the air to form iron oxide and sulfur dioxide; the copper sulfide is not affected. The formation of iron oxide prepares the ore for smelting.

Smelting. The purpose of smelting is to remove the silica, alumina, and some of the iron. This process takes place in a furnace somewhat like the open-hearth furnace used in steel-making. The substances from the roasting furnace are transferred to the smelting furnace and are melted by the high temperature. Some of the iron oxide and all the alumina combine with the silica and form the slag. The copper and remaining iron, still as sulfides, form the *matte*. The slag, being lighter, floats on the matte, and is skimmed off and discarded. In this process the copper is further concentrated so that it is about 45 percent of the matte. So far the copper is still a part of the compound copper sulfide. In the next process, oxidation, copper is finally freed from sulfur.



Courtesy Anaconda Copper Mining Co.

Fig. 50–3. Separation of mineral from worthless rock by oil flotation. Notice the rotating wheels (agitators) and the large bubbles of oil which bring the mineral to the surface.

Oxidation. The molten matte from the smelting furnace is now poured into a pear-shaped furnace similar to the one used in the Bessemer process. Some silica is added, and compressed air is forced in near the base. Copper sulfide reacts with oxygen to form copper and sulfur dioxide which escapes as a gas. The iron forms iron silicate which floats to the surface and is poured off, leaving metallic copper in the converter. This *blister copper*, as it is called, is still impure. It contains some gold and silver and small quantities of other substances. Nevertheless, it is about 99 percent copper and is ready for the final refining process.

The Refining Process. Some of the impurities in blister copper would reduce its effectiveness as a conductor of electricity. Moreover, the gold and silver are worth recovering. The molten blister copper is cast into rectangular slabs which are ready for the refining process. This operation is explained by the following demonstration.

Demonstration 50–1. Electrolytic Deposition of Copper.

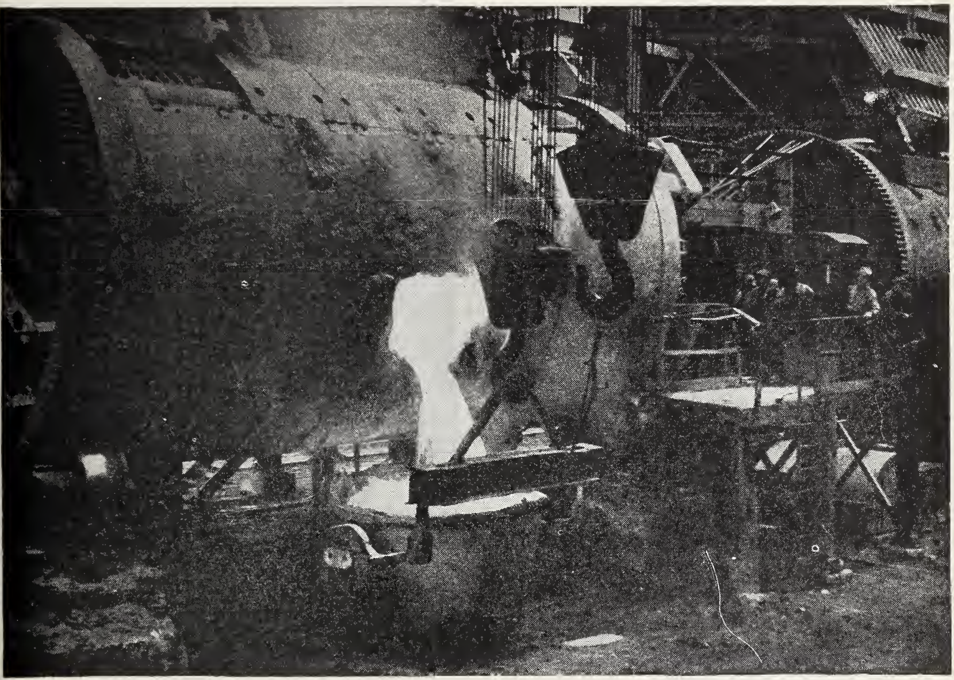
Fill a small battery jar three-quarters full of copper sulfate solution. Attach a strong piece of copper wire to a thin copper sheet about 3 by

4 inches. Suspend the copper sheet in the copper sulfate by hooking the wire on the rim of the jar. In the same manner suspend in the solution an article to be plated; a stick of carbon, such as the positive terminal of a dry cell, can be used. Arrange five dry cells in series. With the switch open, connect the positive terminal to the copper sheet, and the negative terminal through a switch to the carbon rod. Close the switch and allow the current to flow for two or three minutes. Then open the switch. The arrangement is shown in Fig. 50–5.

When you lift the carbon rod out of the solution it will be coated with a red deposit of metallic copper. The copper sheet has lost weight and the rod has gained weight, showing that copper has been transferred from the copper sheet to the carbon. This is *electroplating.* The terminal at which the current enters the solution is called the *anode;* the terminal at which it leaves is called the *cathode.* In the demonstration the copper sheet is the anode and the carbon rod is the cathode. Note that *copper is deposited on the cathode.*

Let us now return to the refining process. A number of rectangular slabs of blister copper are connected in parallel and placed in a lead-lined tank containing copper sulfate solution. These slabs are the anode. A number of thin sheets of pure copper are also connected in parallel and suspended between the anode slabs. The sheets of pure copper form the cathode. The arrangement is shown in Fig. 50–6.

The anode is then connected to the positive terminal of a direct-current supply, and



Courtesy Anaconda Copper Mining Co.

Fig. 50–4. Pouring molten copper from a converter.

the cathode to the negative terminal. As the current flows, pure copper is transferred from the anode to the cathode. The current is then cut off, and the cathode sheets are removed from the tanks and washed.

The cathode sheets are 99.9 percent pure copper. They are melted and cast into molds. The impurities are left behind; from them the gold and silver are extracted.

Uses of Copper. Copper has many useful physical and chemical properties not found in any other common metal. In particular, it resists corrosion, and it is a good conductor of electricity.

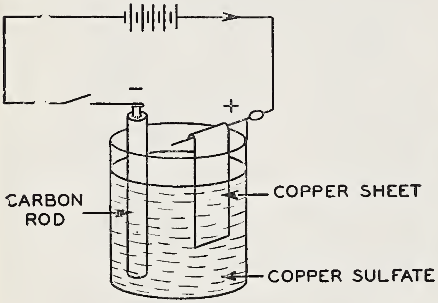


Fig. 50–5. Copper plating. Battery jar ¾ full of copper sulfate. A thin copper sheet is secured to a stout wire, and the wire is suspended from the rim of the jar. Cathode is a carbon rod. Five dry cells arranged in series, and a switch in the circuit.

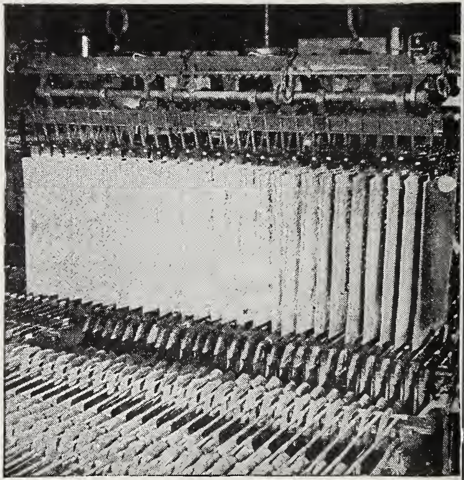
Because of their noncorrosive property, copper and copper alloys, such as brass and bronze, are used in plumbing. But 50 percent of the copper manufactured in the United States is used for cables and wires in the transmission of electricity.

To make copper wire, bars of refined copper are heated and then rolled to form a rod. The rod is then drawn through a series of dies until its diameter has been reduced to the required size.

Copper in Canada. Although the output of copper is far below that of steel, the large deposits in Ontario, Quebec, Manitoba, Saskatchewan, and British Columbia supply our needs and allow us to export. About 264,000 tons of copper are produced annually in Canada, which is about 10 percent of the world's supply.

ZINC

Zinc is a metal that has many uses. It is not as familiar to us as are copper and lead because the pure metal is seldom used. Zinc is extensively used as galvanized iron and in the form of alloys, such as *brass* and *bronze*. The most common zinc ore is *zinc blende*.



Courtesy Anaconda Copper Mining Co.

Fig. 50–6. Lifting pure copper cathodes out of an electrolytic tank.

Zinc can be manufactured by an electrolytic process, but it is more commonly obtained by *distillation*. In the latter process zinc oxide mixed with coal dust is placed in clay retorts. The retorts are heated by a fuel gas, and the coal reacts with the oxide, giving carbon monoxide and zinc, which is vaporized and then condensed. The condensed molten metal is then poured into molds to solidify.

Uses of Zinc. Zinc is used most extensively in the manufacture of brass. Brass is an alloy of zinc and copper. It is harder and stronger than either of these metals and is used for tubes and fittings. Another alloy of zinc is called *white metal.* It consists of zinc, copper, aluminum, and magnesium. Molten white metal is *die-cast;* that is, it is forced under pressure into a steel die, where it solidifies. The door handles and the radiator grills of automobiles are cast in white metal and then electroplated with chromium or nickel to give them a high polish. Other white-metal products include the frame and agitator of the washing machine, the frame of the electric fan, and some lamp bases.

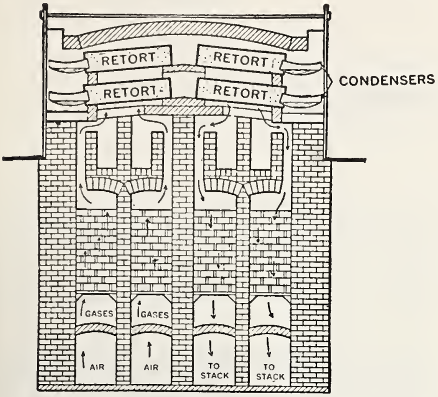


Fig. 50–7. Manufacture of zinc by distillation. The retorts containing zinc oxide and coal dust are heated by hot gases.

Galvanized iron is sheet iron or steel which has been dipped into molten zinc. The coating of zinc prevents the steel from rusting.

Because it has few uses in the unalloyed form, zinc is a little-known metal. Sheet zinc is used in making the containers of dry cells; and in Demonstration 23–3 zinc was used in the preparation of hydrogen.

THINGS TO REMEMBER

The chief copper ores are *malachite, chalcocite,* and *copper pyrite.*

In the *manufacture of copper,* the ore is concentrated, roasted, smelted, oxidized, and refined.

In *electroplating,* copper is removed from the anode and deposited on the cathode.

Copper is used chiefly as a *conductor of electricity.*

Brass and *bronze* are alloys that contain copper and zinc.

Zinc is manufactured by distillation.

White metal, an alloy of zinc, is made into a variety of articles by die-casting.

QUESTIONS

A

1. Name three ores of copper and one ore of zinc.
2. Name the five essential operations in extracting metallic copper from copper ore.
3. Explain the terms: (*a*) anode; (*b*) cathode.
4. Name three provinces in which copper is found. Which is the major producer?
5. What is galvanized iron?

B

6. (*a*) Describe the oil-flotation process.
   (*b*) What is the purpose of this process?
7. Describe the process of smelting copper.
8. Explain how copper matte is converted to blister copper.
9. What is white metal, and how is it used?

Chapter 51

ALUMINUM AND MAGNESIUM

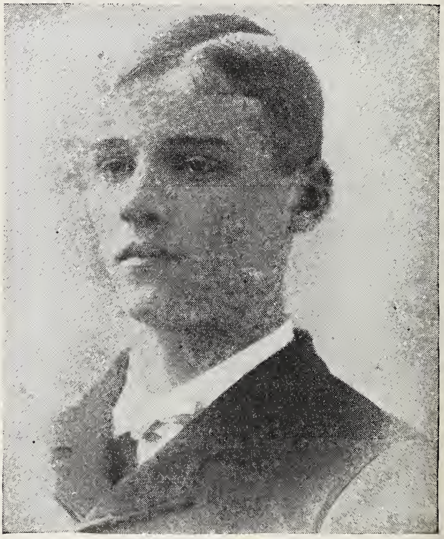
Aluminum and magnesium are the lightweight metals. Aluminum weighs about one-third as much as iron, and magnesium is lighter than aluminum. They are among the most abundant metals in the earth's crust, aluminum being almost twice as abundant as iron. In spite of their abundance, they were for many years unknown as metals. It was not until electric power was developed that they could be produced. The aluminum industry began as late as 1886, and the magnesium industry still later. Before that time these metals were not manufactured because, unlike copper, iron, and zinc, they could not be obtained by heating their ores with coke.

Aluminum occurs in clay; with electric power one shovelful of clay can be made to yield a pound of aluminum. Magnesium occurs in sea water; 800 pounds of sea water will yield a pound of magnesium.

When aluminum was first produced there were few uses for it because it was not strong. But years of research have produced aluminum and magnesium alloys that are stronger than some steels.

ALUMINUM

Aluminum occurs as the mineral alumina, or aluminum oxide, and is usually found in combination with other minerals. Alumina was well known at the end of the 18th century. Even at that time chemists tried to extract aluminum from it. At first it looked as though the process would be simple—just a matter of breaking the bonds between aluminum and oxygen. The chemists found, however, that these bonds could not be broken by ordinary methods. A far more active substance than carbon was needed to pull the oxygen away from the metal.



Courtesy Aluminum Company of America

Fig. 51–1. Charles Martin Hall at the time of his graduation from Oberlin College in 1885.

Oersted, a Danish physicist, tried using potassium and in 1825 he succeeded in breaking the bonds. But aluminum obtained in this way cost more than $500 a pound, which made it more precious than gold or silver. The first article made of aluminum was a rattle presented to the infant son of Napoleon III. It was not until Charles Martin Hall, an American, discovered an easier way to break the bonds between aluminum and oxygen that the metal could be produced at a lower cost.

Charles Martin Hall. As a young college student Charles Hall read the literature on the new metal and determined to be the first to make cheap aluminum. In his spare time he worked on this problem in his father's woodshed. The neighbors complained that he was "always cooking something." At Oberlin College his chemistry professor encouraged him by offering him equipment and materials.

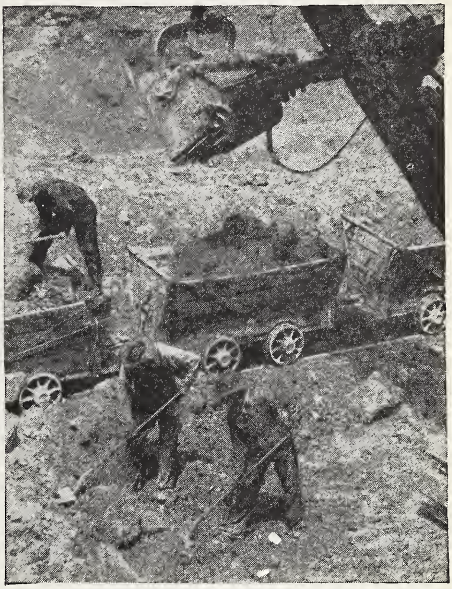
The idea came to Hall that the bonds of aluminum and oxygen might be broken by electricity. But for this process the alumina must be in solution. After many trials and disappointments Hall tried cryolite as a solvent. *Cryolite* is a mineral that looks like ice and is found only in Greenland. It melts at a low temperature and dissolves alumina easily. Hall melted cryolite in a carbon crucible, added alumina, and passed a current through the solution. At the bottom of the crucible he found silvery buttons of aluminum. His process was successful!

In 1886, when he was only twenty-two years old, Hall patented his process. It happened that at almost the same time a young Frenchman named Héroult had by accident independently made the same discovery by the same method. Thus science is seen to advance at about the same pace in many countries. Often a scientific discovery is made independently at almost the same time by two or three different persons. In the United States, credit for the discovery of the aluminum process is given to Hall; in France, the credit is given to Héroult.

After Hall's discovery the price of aluminum dropped sharply. Today it is approximately 15 cents a pound.

INDUSTRIAL PREPARATION OF ALUMINUM

Mining. Clay contains alumina, but clay is a low-grade ore and cannot be worked profitably. The high-grade ore called *bauxite* may contain as much as 50 percent aluminum. Bauxite may be white or deep red; it may be a fine powder or a hard rock; it may occur near the surface or underground.



Courtesy Aluminum Company of America

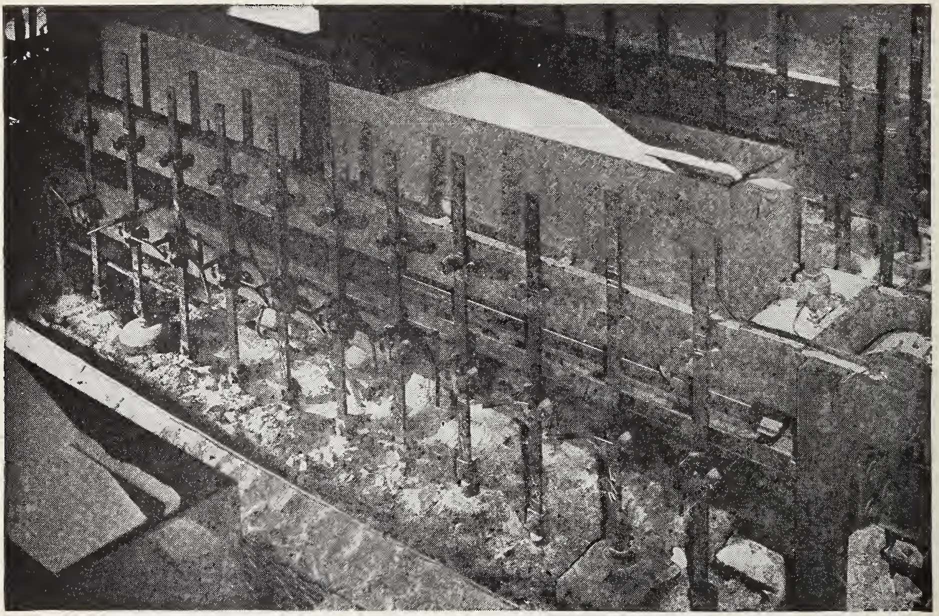
Fig. 51–2. Surface mining of bauxite.

Bauxite Deposits. Bauxite deposits are found in many parts of the world, the best bauxite coming from tropical countries. There are no deposits in Canada and the largest aluminum smelter in the world, at Arvida, Quebec, draws its supply from British Guiana. Rich deposits are found in France, India, Malaya, the East Indies, Australia, the African Gold Coast, Brazil, Dutch Guiana, and Jamaica.

Arvida supplies over one quarter of the world's aluminum, making Canada the second largest producer. Canada owes her position to the fact that large quantities of hydroelectric power are found near deep-water ports. To meet the growing demand a new smelter is now being built at Kitimat, B. C., where over a million and a half horsepower will be made available by damming the Nechako River system. The bauxite will come from Jamaica.

Purifying the Ore. Alumina must first be separated from impurities in the ore. This is done by crushing the ore to a powder and placing it in tanks where it is treated with lye and steam. The steam agitates the mixture and condenses, and the alumina dissolves in the lye. Such impurities as silica and iron oxide do not dissolve. The clear solution is taken to another tank where it cools. Crystals of alumina solidify and are removed from the solution.

Separation of the Metal. The final operation is carried out in electrolytic cells. Each cell, 10 feet wide, 16 feet long, and 1½ feet deep, is a steel shell lined with carbon. The carbon lining is the cathode. The current is led into the cell by carbon anodes suspended overhead.



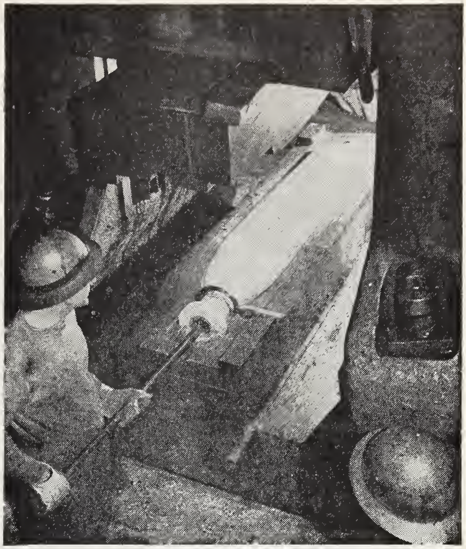
Courtesy Aluminum Company of America

Fig. 51–3. An electrolytic cell in operation. Note the tops of the carbon anodes above the crust of alumina. Notice also the charge of alumina ready to be dumped into the cell.

Cryolite is first put in the cell and melted by the current. Alumina is added; it dissolves in the molten cryolite, and oxygen is released at the carbon anodes. The aluminum collects at the bottom of the cell. It is transferred to ladles and cast into pigs. Each pig weighs 50 pounds.

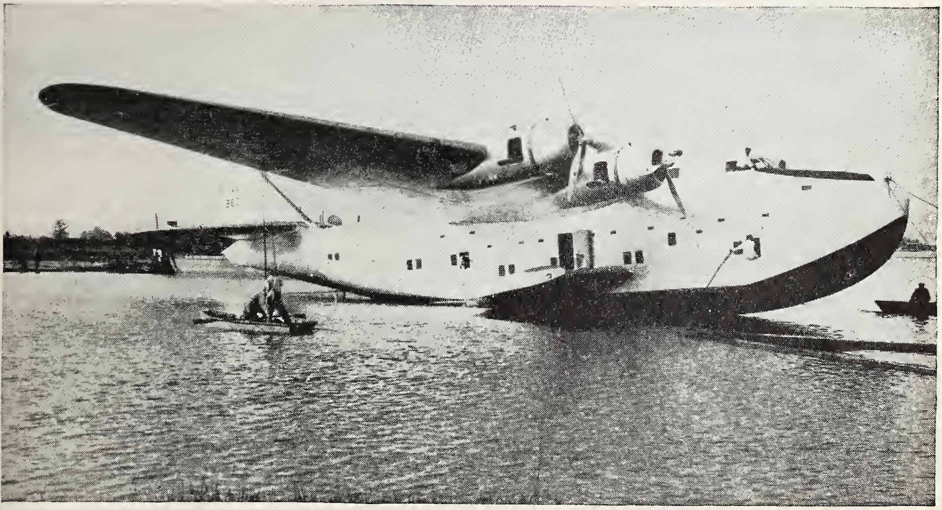
Fabricating the Metal. Aluminum can be rolled, forged, cast, extruded, drawn, or welded. Few other metals can go through so many processes. Aluminum can be *rolled* like steel, either into flat sheets or into all the shapes required in construction work. Or it can be *extruded*, in much the same way as toothpaste is squeezed out of a tube, to form a flat ribbon. In this process the hot aluminum is forced under tremendous pressure through holes or tubes of any desired shape. In this way tubes used in an engine or plane can be made without joints or seams. In *forging*, the hot metal is hammered into shape by the impact of mechanically operated hammers. Propeller blades, for example, are made in this way.

Alloys. Although aluminum is used for many purposes, the metal is seldom used in pure form because it has little strength. Aluminum is therefore usually found in alloys that make it stronger and tougher. The alloys are made by adding magnesium, copper, manganese, and chromium. The first, and probably the



Courtesy Aluminum Company of America

Fig. 51–4. Forging an aluminum airplane propeller blade. Notice the electrically operated hammer used for pounding in this operation.



Courtesy Aluminum Company of America

Fig. 51–5. Aluminum is extensively used in aircraft construction.

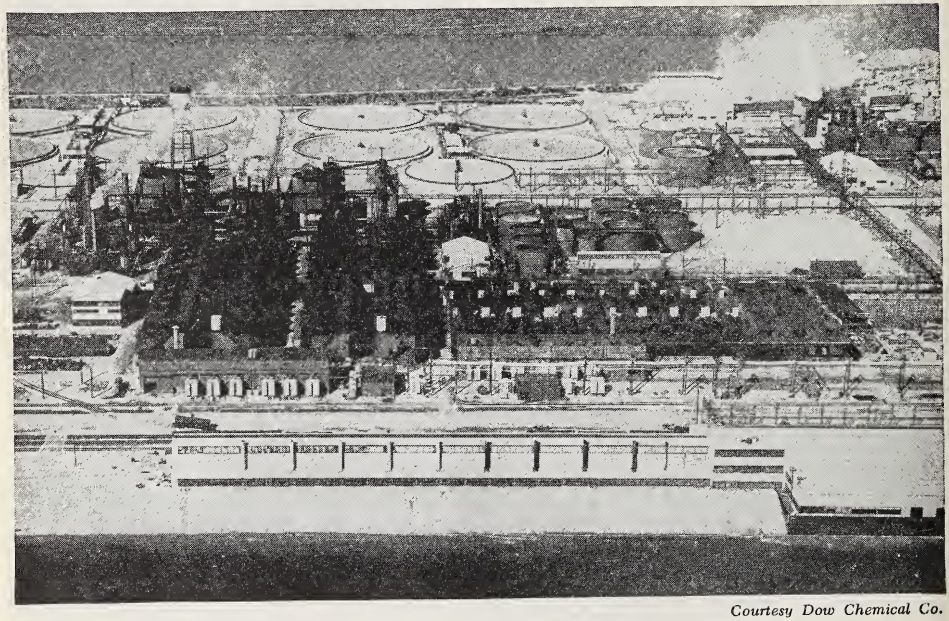
best-known, alloy of aluminum is *duralumin.* When rolled, duralumin is much stronger than pure aluminum, and it can be further strengthened and hardened by heat treatments.

The lightness and strength of these alloys make them very valuable in aircraft construction. About 90 percent of the materials used in some bombers is aluminum alloys.

There are many other uses of aluminum. Airplanes, trucks, buses, huge parts for Diesel engines, pots and pans, lawn mowers, chairs, and even bridges are only a few examples of the wide applications of aluminum.

MAGNESIUM

Magnesium is the lightest of all the structural metals, and for some special purposes magnesium alloys are preferable to aluminum alloys. The largest magnesium plant in the United States is in southern Nevada, where vast deposits of magnesium ore, called magnesite or magnesium carbonate, are found.



Courtesy Dow Chemical Co.

Fig. 51–6. Magnesium from sea water. The circular tanks in the background contain sea water to which lime has been added. The oyster-shell storage is shown on the right in the background and also the kilns for converting the shells to lime. In the foreground are the filters and evaporators where magnesium chloride is concentrated, and also the cell buildings where the metal is obtained.

Magnesium from Sea Water. During World War II so much magnesium was needed for airplanes, incendiary bombs, and other war equipment that a plant for extracting magnesium from sea water was built at Freeport, Texas. There for the first time metallurgists used sea water as a source of metals.

In the Freeport plant, oyster shells collected from Galveston Bay are heated to form lime which is added to sea water in large tanks. A reaction takes place and the magnesium is precipitated as an insoluble compound. This compound is then separated from sea water and converted into magnesium chloride. The magnesium chloride is melted, and a current is passed through it. Molten magnesium is formed at the cathode, and chlorine at the anode. The light magnesium is skimmed off and poured into molds to form 17-pound pigs.

Properties of Magnesium. Like aluminum, magnesium can be rolled, cast, welded, and extruded. In finely divided form or thin strips it burns in oxygen. In bulk, however, it is difficult to ignite, and it is therefore quite safe in aircraft construction.

Magnesium Alloys. Like aluminum, magnesium has little strength, but with the addition of small amounts of aluminum and manganese it can be made as strong as steel. About 80 percent of our magnesium is used in aircraft construction. Magnesium alloys are substituted for steel in the construction of airplane engines because they are lighter than steel. The ordinary locomotive develops about one horsepower for every one hundred pounds of engine weight. The airplane engine used by Wilbur and Orville Wright was made of aluminum-copper alloy; it developed one horsepower for every 13 pounds of engine weight. The modern airplane engine, made of a magnesium alloy, develops one horsepower for each pound of engine weight.

Courtesy Westinghouse Corp.

Fig. 51–7. Magnesium is used for most of the fuselage of this U.S. Navy jet plane.

THINGS TO REMEMBER

Charles Martin Hall discovered the modern method of separating aluminum from the oxygen in alumina.

Aluminum is obtained from *bauxite*.

Aluminum can be *rolled, forged, cast, extruded, drawn,* and *welded.*

The best-known alloy of aluminum is *duralumin,* which is used in airplane construction.

Magnesium is extracted from sea water.

Magnesium alloys are used in the construction of airplane engines.

QUESTIONS

A

1. Explain the terms: (*a*) bauxite; (*b*) alumina; (*c*) cryolite.
2. What is meant by: (*a*) forging; (*b*) extrusion of aluminum?
3. What is duralumin, and why is it preferred to pure aluminum for most purposes?
4. Why is magnesium used in the construction of aircraft?
5. Name a common ore of aluminum and one of magnesium.
6. Why are oyster shells used in the manufacture of magnesium from sea water?

B

7. Explain why aluminum cannot be extracted from aluminum oxide in a blast furnace.
8. How did Charles Martin Hall first obtain aluminum from its ore?
9. Explain how aluminum metal is obtained in an electrolytic cell.
10. Explain how magnesium is extracted from sea water.

Chapter 52

GLASS AND CEMENT

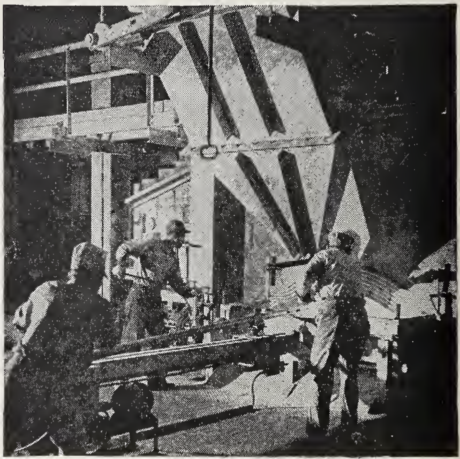
In the preceding chapters of this unit the metals iron, steel, copper, zinc, aluminum, and magnesium are discussed as construction materials. But metals are not the only materials used for construction purposes. As already stated, the supply of metallic ores is dwindling. Therefore, whenever possible, the unlimited resources of sedimentary rock should be used instead of metals.

Limestone is the ideal rock for construction purposes. When strongly heated, it decomposes to form lime; and hot lime can be combined with silica or sand to form hard, durable silicates. Vast quantities of sand and limestone are used in the manufacture of both glass and concrete.

Glass is transparent, and it is not affected by ordinary chemicals. When heated it becomes plastic. Thus it can be blown to make containers of all shapes and sizes; and it can be used to transmit light, as in windowpanes and lenses. But glass can also be given other useful properties, as we shall see shortly. Concrete, on the other hand, forms an artificial rock and is therefore used in large-scale construction. Like ordinary rock, concrete is slowly eroded by the forces of nature, but this does not detract from its usefulness as a building material.

GLASS

Glassmaking has been an industry for at least three thousand years. For centuries glass was made according to secret formulas discovered by trial and error. Yet Egyptian glass made three thousand years ago has almost the same composition as the soda-lime glass used today. It was not until the beginning of the present century that much improvement was made in the manufacture of glass.

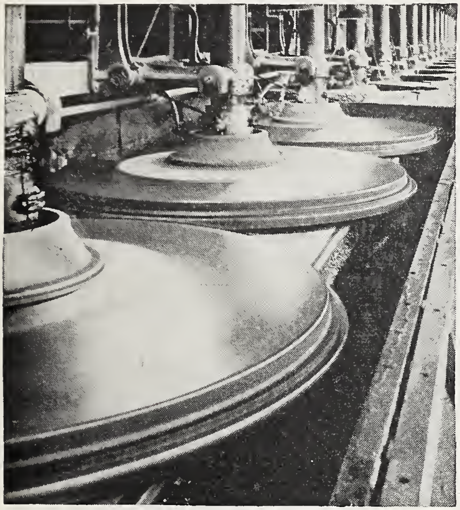


Courtesy Libby-Owens-Ford Glass Co.

Fig. 52–1. A step in the production of glass. Here the raw materials used to make glass are being melted together.

Window glass was invented sometime during the Middle Ages. The windows in some of the medieval cathedrals in Europe are priceless works of art. The glass blowers knew how to color their glass with rich reds, yellows, greens, blues, and purples.

From the 13th to the 18th century Venice was the center of the glassmaking art. The Venetian craftsmen have left us many beautiful glass cups and vases. They blew glass in molds, cut it, and decorated it with gold leaf and with a variety of colors. They also knew the value of reheating, or *annealing*, to increase the strength of their glass. And they were the first to make mirrors by depositing a thin coat of silver on the back of a sheet of glass. The Venetian glassmakers guarded their secrets carefully. They took apprentices into their fraternity, or guild, only after they had proved themselves trustworthy. Indeed, at one time, to further guard their secrets, the Venetian glassmakers were kept on the island of Murano, separated from Venice by a narrow strip of the sea, where they were almost prisoners. But secrets cannot be kept forever, and in the 16th and 17th centuries the art of glassmaking spread to France, Germany, and England.



Courtesy Pittsburgh Plate Glass Co.

Fig. 52–2. Grinding and polishing plate glass. The rough glass plates are first ground to uniform thickness with an abrasive of sand and emery. The plates are then polished by felt pads on revolving disks. The pads are covered with ferric oxide, or rouge.

Glassmaking is the oldest American industry. It dates from the settlement of Jamestown. The colonists built a small furnace just outside the stockade and made glass beads to be used in trading with the Indians.

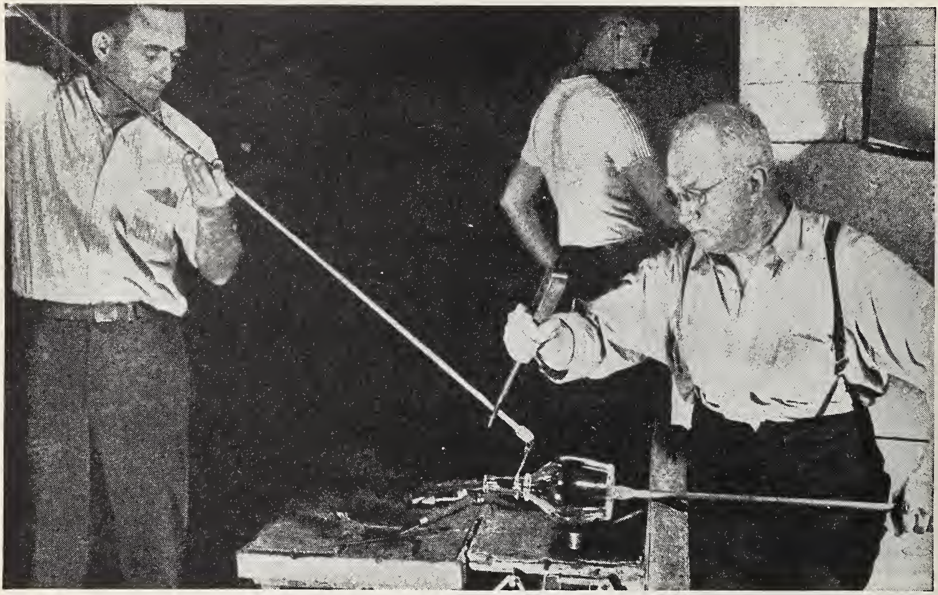
Glass was present in nature long before it was made by man. Natural glass is called *obsidian;* it is usually black, like black bottle glass. Obsidian was formed by the rapid cooling of molten rock. There is a huge deposit of obsidian in Yellowstone National Park. It is about 9 miles long and 5 miles wide, and it rises about 250 feet above the countryside.

Manufacture of Glass. To make ordinary glass, a mixture of sand, lime, and soda is melted in a furnace. Other substances, such as boric oxide or lead oxide, may be added to give special properties. The mixture is placed in an enormous clay pot that holds about two tons of raw material. The pot is heated to about 2800° F. in a furnace and kept there from 36 to 72 hours. The molten glass is then ready for fabricating.

When plate glass is being manufactured, the glass is poured on an iron table, where it spreads in much the same way as batter on a hot griddle. A heavy cylinder is rolled over this mass to flatten it into a uniform sheet. The glass sheet is then annealed in an oven. Finally it is polished with large felt pads, which turn at high speed, using water and fine rouge for polishing.

Most glass products are produced by automatic machinery. One such machine makes electric-light bulbs at the rate of 600 per minute; another makes soft-drink bottles at the rate of 5,000 per minute.

Delicate glassware, such as vases and goblets, is made with a blowpipe just as was done three thousand years ago. The glass blower dips his blowpipe, which is a tube four feet long with a mouthpiece at one end, into the pot of molten glass. A mass of glass collects on the end. He shapes this on a metal table. Then he blows and swings the pipe to enlarge and cool the bubble that forms. The bubble is then put into a mold. More glass is added to the bubble, and the glass is blown into its final shape.



Courtesy Corning Glass Works

Fig. 52–3. Hand blowing. The men are making rings around the neck of a decanter before blowing it into final shape.

Kinds of Glass. During the present century glassmaking has become one of the major industries of the United States. Glass can be made lighter than aluminum or heavier than steel. It can be blown, sawed, knotted, or woven. Possessing these properties, it can be fabricated into an amazing variety of articles.

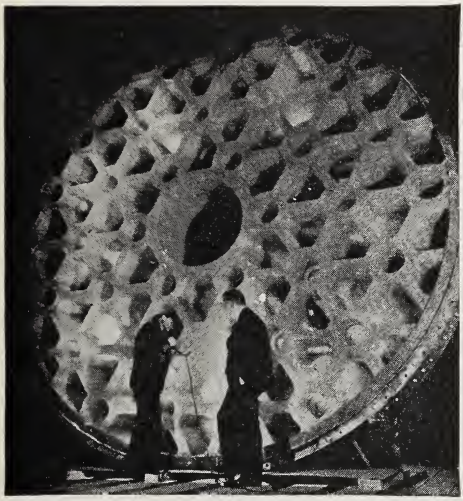
Borosilicate Glass. Borosilicate glass, which is probably the best all-purpose glass, contains boric oxide. It has a higher melting point than ordinary window glass. It can be exposed to a wide range of temperatures without breaking, and it reflects less heat than metal dishes. It is therefore suitable for baking dishes and for laboratory glass apparatus. Pyrex is an example of borosilicate glass.

Safety Glass. Nonshatterable *safety glass* is used for all windows in modern automobiles. It is made by placing a sheet of transparent plastic between two glass plates and exposing the three layers to high pressure until they become one unit. The plastic layer prevents the glass from being shattered if the windshield is broken.

Glass Fibers. Melted glass can be drawn through tiny holes to form a fluffy mass of wool-like fibers. These glass fibers are used in making loose thick mats for insulating walls and roofs of buildings against heat.

Glass fibers can also be spun finer than silk thread—so fine that a pound of fibers would stretch around the earth. Such fibers can be twisted into yarn and woven into bedspreads, tablecloths, fireproof curtains, and sleeping bags.

The Mount Palomar Mirror. The disk of the Mount Palomar telescope, which is in southern California near San Diego, is the largest single piece of glass ever manufactured. It originally weighed about 20 tons. The back of it is in the form of a grid, like a waffle iron, except that the units are triangular, not rectangular. It took eleven years to complete the grinding and polishing of this glass disk, more than five tons of glass being removed.



Courtesy Corning Glass Works

Fig. 52–4. The glass disk in the telescope at Mount Palomar, which weighs about 15 tons, is the largest piece of glass ever made.

Modern Glass. The glass today is quite different from that of years ago. It is no longer a substance from which only windowpanes and tumblers are made. As a result of research, chemists and physicists can give to glass properties that were not thought possible in the 19th century. It can be made to transmit the rays in the visible spectrum or only the infrared rays; it can be given great strength, as in automobile windshields or in watch crystals; its expansion can be made as great as that of steel. Indeed, it is misleading to speak simply of "glass," for there are at least a thousand different kinds. Glass is probably the most adaptable of all materials, and it contributes greatly to our convenience and comfort.

CEMENT

Cement is used in construction work, being second only to steel in importance. It is made from limestone and either clay or slag. The mixture is crushed to a powder, baked, and powdered again. This powder will absorb water to form a synthetic rock that is harder than most natural rocks.

The first cement was made in 1824 by an Englishman named Aspdin, who mixed limestone and clay, burned them in a furnace, and then ground them to a fine powder. When treated with water and allowed to stand, this powder hardened to a yellowish mass that looked like the limestone quarried near Portland, England. The inventor therefore called it *portland cement.*

Manufacture of Cement. Because almost 25,000,000 tons of limestone are needed annually for the cement industry, cement mills are usually located near a good limestone supply. The limestone is blasted by dynamite, and after being crushed it is taken to the plant.

Limestone and dried clay or slag are mixed in the right proportions. The mixture is put into large steel cylinders, loaded with tons of steel balls about the size of walnuts. As the cylinders turn, the tumbling balls pound the mixture to a fine powder. The mixture now looks like cement, but it lacks the necessary binding properties. To gain these properties, it requires heating and further grinding.

Cement Kilns. The mixture is then burned in a rotary kiln. Cement kilns are the largest pieces of rotating machinery used in industry, some being almost 500 feet long. They are set at a slight slope to make the material move from one end to the other, and they are turned by electric motors.

A steady stream of the powdered mixture is admitted at the higher end, and as the kiln slowly turns, it moves to the lower end. There a powerful blast of air carries powdered coal toward the mixture. The coal ignites and heats the kiln to a temperature of about 2700° F. at the burning end. As the raw material passes through the flames, a mass, called a *clinker,* is formed. The clinker drops from the kiln and is carried to a storage pile, where it cools.

Pulverizing the Clinker. The clinker is then crushed to form cement. Again the grinding is done in a battery of rotating cylinders. This time, however, the degree of fineness is very important. The finer the particles, the stronger is the adhesion between them in the finished product. After this operation the particles are so tiny that the cement will pass through a sieve too fine to allow water to pass through it.

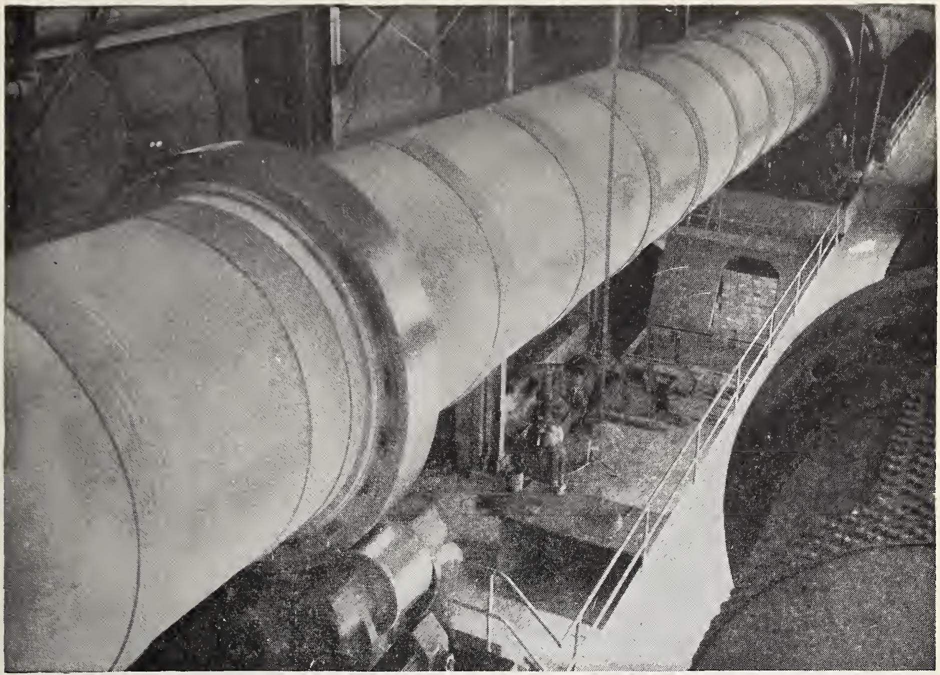
CONCRETE

The purpose of manufacturing cement is to make concrete. Concrete is a paste consisting of cement, sand, gravel or crushed rock, and water. When water is added, the compounds in the cement react with it to form products that cling to the sand and gravel and to each other. Thus a synthetic rock is formed that continues to harden and strengthen for some years.

As concrete remains soft for a short time, it can be poured into a mold of any desired

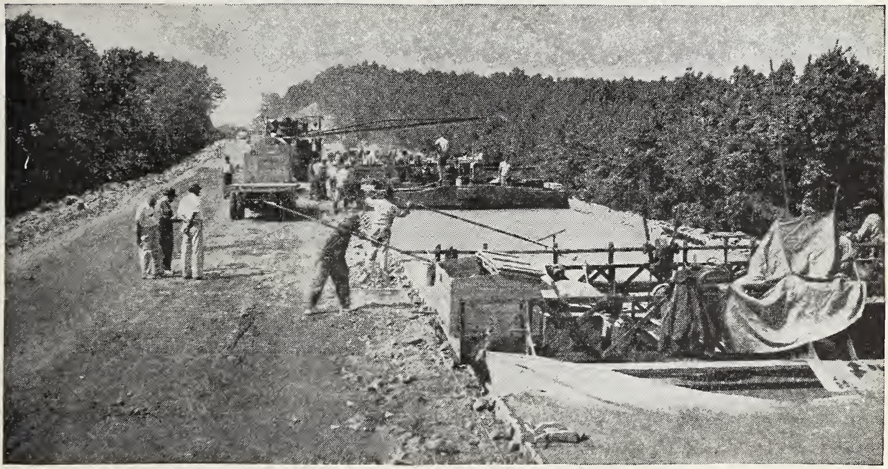
Courtesy Pittsburgh Plate Glass Co.

Fig. 52–5. Modern houses provide for much window space.



Oilways from Esso Standard Oil Co.

Fig. 52–6. A cement kiln may be as long as 500 feet. It is slowly rotated so that the charge falls from the higher to the lower end.



Courtesy Public Roads Administration

Fig. 52–7. Paving a concrete highway.

shape. It is used for every kind of structure. Concrete can withstand a great deal of pressure but little tension or stretch. For large structures it must therefore be reinforced with steel rods or mesh. Concrete that contains mesh is called *reinforced* concrete. Dams, lighthouses, factories, airports, sea walls, churches, schools, hospitals, hotels, and highways are made of reinforced concrete.

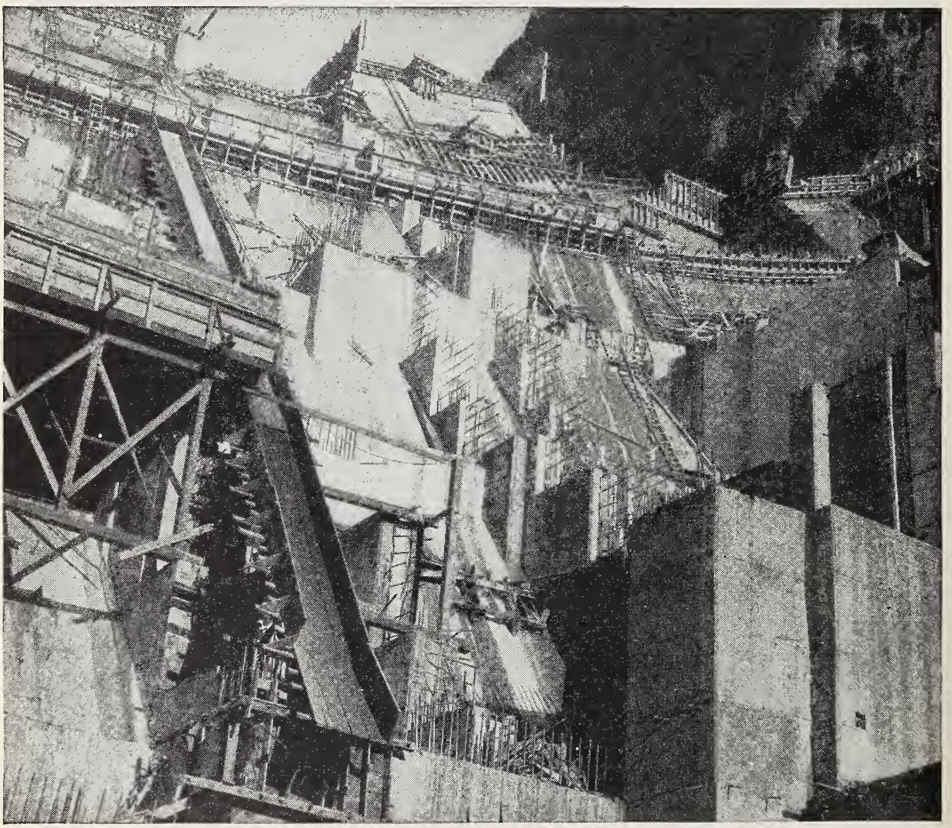

Courtesy U.S. Bureau of Reclamation

Fig. 52–8. The Hoover Dam rises step by step in blocks of reinforced concrete.

Highways. More cement is used in building concrete highways than in any other kind of construction. A mile of road 10 inches thick and 20 feet wide requires 6,500 tons of cement. More than 100,000 miles of concrete highways have been constructed in the United States. With the number of automobiles on the roads increasing steadily, the present highways are inadequate, and probably road construction will take the largest part of manufactured cement for many years.

Dams. The most impressive of the concrete structures are enormous dams, such as Hoover Dam and Grand Coulee Dam. Hoover Dam was built on the Colorado River in one of the driest and hottest regions in the United States. As explained in an earlier chapter, the mighty Colorado cut many gorges through the rocks in its path, the deepest being the Grand Canyon. Before the dam was built, the Colorado, when fed by the melting snows of the Rockies in the spring, often overflowed its banks and flooded the country for miles around. At other times, it dried up so that men could walk across its bed. During these times of drought the crops withered and livestock was slaughtered to save the precious water for home use. This harmful cycle of flood and drought was a common occurrence.

The Hoover Dam project was one of the most ambitious engineering plans ever conceived by man. The dam creates a lake large enough to store the entire flow of the Colorado River for two years. This lake supplies water for irrigation even when there are no summer rains, provides electric power for the development of the rich mineral regions of Nevada and Arizona, and controls the spring floods and prevents erosion of land and destruction of crops.

To build the dam across the canyon, the Colorado had first to be led into another channel. Canyon walls had to be dynamited, and it was necessary to dig down to solid rock 135 feet below the river bed. The dam is more than half as tall as the Empire State Building in New York, and is nearly a quarter of a mile long.

The Tennessee Valley Authority. The Tennessee Valley system is a network of dams along the Tennessee River. It is a government project to stop soil erosion and to provide power.

The average rainfall in the Tennessee Valley is 52 inches a year. Under the impact of so much rain there was a great deal of erosion, and much fertile soil was carried to the Mississippi River and into the sea. Today the water is stored behind concrete dams in ten lakes, and at each lake generators convert water power to electricity. The Tennessee Valley Authority is the largest power-producing system in America.

THINGS TO REMEMBER

The *Venetians* were famous glassmakers from the 13th to the 18th century.

Natural glass is called *obsidian.*

Ordinary glass is made from sand, lime, and soda.

Borosilicate glass is used in making laboratory glassware and baking dishes.

Safety glass has a layer of plastic between two layers of glass. It is nonshatterable.

Cement is made by pulverizing a mixture of limestone and clay or slag, heating the mixture in a furnace, and then pulverizing it again.

Concrete is a paste of cement, sand, and gravel.

Reinforced concrete is used in constructional work, such as highways and dams.

QUESTIONS

A

1. What is obsidian?

2. What is safety glass, and how is it made?

3. State the difference between cement and concrete.

B

4. How is ordinary glass made?

5. (*a*) How does borosilicate glass differ from ordinary glass?
  (*b*) Why is borosilicate glass used in making cooking utensils?

6. Write a short account of the Venetians as glassmakers.

7. Describe the operation of the rotary kiln.

REVIEW QUESTIONS ON UNIT 10

A

1. State which of the following are elements and which alloys: (*a*) iron; (*b*) steel; (*c*) glass; (*d*) brass; (*e*) zinc; (*f*) cement.

2. Name a common ore of: (*a*) iron; (*b*) copper; (*c*) zinc; (*d*) aluminum; (*e*) magnesium.

3. What industries do you associate with each of the following places: (*a*) Arvida; (*b*) Sydney; (*c*) Labrador-Quebec; (*d*) Kitimat?

4. Which of the following metals cannot be obtained by heating the ore with coke: (*a*) magnesium; (*b*) iron; (*c*) zinc; (*d*) aluminum?

5. In electrolytic refining the metal is always formed at the —?—.

6. Which metal is extracted by the oil-flotation process? Why?

7. Apart from the air needed for making fire, which of the following operations need large quantities of air? The manufacture of: (*a*) iron; (*b*) steel; (*c*) aluminum; (*d*) glass.

8. Name the chief metal in the following alloys: (*a*) bronze; (*b*) stainless steel; (*c*) duralumin; (*d*) white metal.

9. Compare the physical properties of the metals copper and aluminum.

10. State three properties of glass which are not found in most other substances.

B

11. Explain the purpose of: (*a*) the blast furnace; (*b*) the open-hearth furnace.

12. (*a*) What are steel alloys?
(*b*) Name three such alloys and give their uses.

13. Compare the uses of carbon in the blast furnace and in the manufacture of aluminum.

14. Explain the part played by limestone in: (*a*) the manufacture of glass; (*b*) the manufacture of cement.

15. Give the reasons why Canada, although it has no bauxite deposits, has become a leading producer of aluminum?

16. The Hoover Dam is 660 feet thick at the base and is only 45 feet at the top. Explain why.

17. Explain how the high temperatures are obtained in the manufacture of: (*a*) iron; (*b*) aluminum; (*c*) cement; (*d*) glass.

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Unit 11

THE CHEMICAL NATURE OF THINGS

53. CHEMICAL ACTIVITY
54. THE SHORTHAND OF CHEMISTRY
55. WHAT ARE IONS?
56. CHEMICAL INDUSTRIES
57. CHEMISTRY AND THE CONSUMER

Chapter 53

CHEMICAL ACTIVITY

The systematic study of chemistry did not get under way until the 19th century. We have already discussed the important contribution of Lavoisier in the field of combustion (see page 202) at the end of the 18th century. At the time of Lavoisier's death an Englishman named John Dalton was pondering the subject of atoms. In 1808 he published his Atomic Theory which was destined to have more repercussions than any other scientific theory ever formulated. As stated on page 21, the Greek philosophers first introduced the idea of atoms. But their ideas were very vague. They thought of atoms as building blocks of matter and they believed that building blocks of the same element could have different sizes and shapes. Then for centuries the Greek atoms were forgotten until John Dalton revived the idea in a very different form.

What is Dalton's Atomic Theory? Dalton's theory can be summarized in four simple sentences. First we will state the theory and then discuss one of the statements in it. Dalton said that:

(1) Matter is composed of atoms which are indestructible particles;
(2) All atoms of the same element have the same weight and are alike in properties;
(3) Atoms of different elements differ in weight and properties from those of other elements;
(4) Compounds are formed by a combination of atoms of different kinds.

The first item in his theory was similar to the Greek idea, stated 2000 years earlier. But the second item is far different. Dalton's assumption that all atoms of the same kind are alike was one of the most important scientific statements made up to that time. In the first place, it followed from this statement that there were such things as atomic weights, a subject already discussed on page 21. Dalton was the first scientist to work experimentally on the determination of atomic weights.

But the statement meant far more than this. Let us see how Dalton used his theory to discover some natural laws. The first of these discoveries was known as the Law of Conservation of Mass.

The Law of Conservation of Mass. Dalton reasoned as follows. When atoms take part in a chemical reaction they simply change partners—they attach themselves to a different kind of atom and form a different kind of molecule. The atoms do not change in weight so that the total weight of all the atoms must be the same after an experiment as it was before it. Dalton expressed this idea in simple language when he said, *There is no change of weight in any chemical reaction.* This he called the Law of Conservation of Mass.

This law is probably the most important law in chemistry. It means that in a chemical reaction the weights of the starting substances are exactly the same as the weights of the products. Now this is precisely the assumption we make in chemical computations—it is at the basis of all work on chemical analysis. When a substance is analyzed we find the percentage weights of the constituent elements. This is a basic process in chemistry and yet it could not be done until the above law was established. If you take a more advanced course in chemistry you will solve many problems based on the law. For us, we will be content to verify the law by experiment.

Demonstration 53–1. To Verify the Law of Conservation of Mass.

Pour some silver nitrate solution into a flask. Almost fill a small test tube with hydrochloric acid and lower it into the flask by a cotton thread. Secure the thread by a stopper as shown in Fig. 53-1. Weigh the flask and contents. Tilt the flask so that the two solutions mix. A white precipitate is formed. Weigh the flask and contents again.

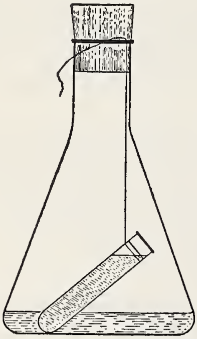


Fig. 53–1. Verifying the law of Conservation of Mass.

The formation of a white precipitate proves that a new substance has been formed; in other words, a chemical change has taken place. And yet the total weight remains the same. This verifies the law.

What is a Scientific Law? As you continue with your science courses you will learn a good many laws. What are they? How important are they? First of all, let it be said that a scientist is always trying to understand nature—trying to make nature divulge her secrets. Within the past 200 years scientists have learned a great deal about nature. But there is also a great deal they do not know. There are still many fields to be investigated if you decide to become a scientist. When a scientist discovers something about nature he expresses his discovery in the form of a law. In other words, a scientific law is a way of telling us how nature behaves. Notice that a scientific law is very different from a civil law or a law on the statute book. A civil law is man-made; it is designed to protect us as members of a community or state. A scientific law, on the other hand, is independent of man—it is discovered, not made.

What is the Scientific Method? How does the scientist succeed in unfolding the secrets of nature? First of all, he performs a large number of experiments concerned with his particular problem. Then out of his experimental work a pattern of behavior may emerge. He then makes a guess on the way nature operates. This guess is called a *hypothesis*. If the guess or hypothesis serves to explain a good many phenomena, the hypothesis is called a *theory*.

Once a theory is established, it can be used to delve into the unknown. It is a powerful pioneering tool. For instance, Dalton discovered three scientific laws by means of his atomic theory.

Let us note in passing that Dalton could not prove his theory by experiment. He could not weigh atoms, nor could he measure the sizes of atoms. That is to say, his theory was a guess. But—and this is important—the deductions he made from his theory *could* be tested by experiment. We ourselves have tested the Law of Conservation of Mass by experiment. Such deductions which meet the test of experiment help to establish the truth of the theory.

The Law of Constant Proportions. Dalton had great faith in his theory and he used it to discover other natural laws. The only one we shall consider at this time is the Law of Constant Proportions. Dalton arrived at this law in the following way:

Suppose two compounds have precisely the same properties. The properties of a compound depend on the *kind* of atoms and the *number* of atoms it contains. If two compounds are alike it follows that they must be made up of the same kind and number of atoms. But all atoms of the same element have the same weight. Therefore these two compounds must have the same composition by weight.

From this argument Dalton drew the following conclusion. *A given compound always contains the same elements in the same fixed proportion by weight.* This he called the Law of Constant Proportions.

This law is also one of the basic laws of Chemistry. Let us see what it means by considering the compound copper oxide. Copper oxide, you may recall, is a black powder. It can be made in at least four entirely different ways. If copper oxide is analyzed it is found to consist of 80 percent copper and 20 percent oxygen. No matter if it is made in Canada, or China, or in England, it still has the same composition.

This is a very remarkable thing. Chemical compounds are constant in their composition. New compounds are being made and analyzed by research chemists every day. These chemists write up their method of making them in a Chemical Journal. If a chemist on the other side of the world wishes to make them, he can. And he will find precisely the same percentage compositions. Probably you now begin to understand what is meant when chemistry is called an exact science.

John Dalton (1766-1844). Dalton's Atomic Theory was the starting point for a great deal of research work upon the atom. It led directly to the present day knowledge of atomic structure and even to the knowledge that enabled scientists to smash the atom. Who was this man Dalton?

John Dalton, a Quaker, lived in the Lake District in England. His father, a weaver, was too poor to pay for the education of his son. John Dalton left his village school at 11 years of age. But he had a keen mind and was ambitious. He taught himself Latin, Greek, French, mathematics, and natural philosophy, as science was then called.

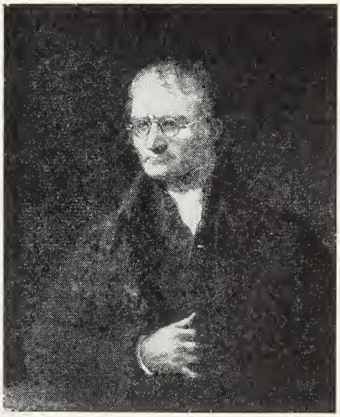


Fig. 53–2. John Dalton (1766-1844).

He became a teacher at an early age and remained a teacher for the rest of his life. Dalton was a reserved, unassuming, uncouth, and frugal man. He used to take long solitary walks in his mountainous neighborhood, and it was during these walks that he meditated on his atomic theory. His achievement is extraordinary because he became one of the greatest scientists in spite of his deficient educational background.

Towards the end of his life, when the value of his Atomic Theory was beginning to be recognized, honors were showered freely upon him. He was made a Fellow of the Royal Society—the highest scientific distinction in England—and, at 68 years of age, the British government recognized his merit and granted him a pension of $1500 a year.

Chemical Activity. In his law of Constant Proportions Dalton referred to the composition of compounds. A question that might well be asked at this time is, Why are compounds formed? Or, expressed another way, What is chemical activity? These are important questions and they cannot be answered until we have more chemical knowledge. But we can move in that direction by considering more chemical reactions. Let us turn back to page 207 and refer again to the preparation of hydrogen. The experiment on this page proves that hydrogen can be made by a reaction between the metal zinc and sulfuric acid. Where does the hydrogen come from in this reaction? Clearly it must come from either the zinc or the acid. It cannot come from the zinc because zinc is an element. What then, is an acid?

What is an Acid? Acids are an exceedingly important group of compounds—there are literally hundreds of acids. And they all contain hydrogen. A simple way of testing for an acid is to use blue litmus paper. Dip the litmus into the solution and if the paper turns red, the solution is an acid.

If we were to be specific we would say, *An acid is a substance which contains hydrogen, this hydrogen being replaceable by a metal to form a salt.* This definition involves another class of substances called salts, —acids and salts are closely related. In fact, a salt is *always* formed when the hydrogen of an acid is replaced by a metal. Salts are so important that we had better make one, or even two, of them.

Demonstration 53–2. To Make a Salt.

Place a few pieces of zinc in a beaker and then pour enough dilute sulfuric acid into the beaker to cover the zinc. Notice the brisk chemical action and the formation of bubbles of hydrogen.

After two or three minutes filter the solution and catch the clear solution in an evaporating dish. Put the dish aside for a day and then notice the long crystals that have formed in the dish.

The crystals are zinc sulfate, a salt. We can express the reaction by the equation,

zinc + sulfuric acid → zinc sulfate + hydrogen

A sulfate is a salt formed from sulfuric acid. There are many sulfates—sodium sulfate, calcium sulfate, magnesium sulfate, ferrous sulfate (*ferrous* is a word the chemist uses for iron).

Salts of Other Acids. Sulfuric acid is by no means the only acid that will react with metals. Let us try hydrochloric acid. Salts formed from hydrochloric acid are called *chlorides*. The most plentiful of all salts is sodium chloride. For this reason it is called common salt or just salt.

Demonstration 53–3. To Make Magnesium Chloride.

Place a piece of magnesium ribbon in a test tube. Pour a little dilute hydrochloric acid in the test tube. Notice the exceedingly vigorous reaction and the evolution of hydrogen. Pour the

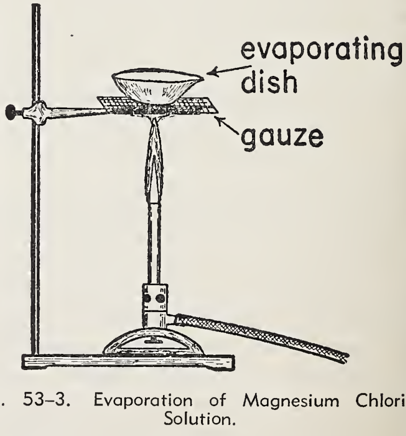


Fig. 53–3. Evaporation of Magnesium Chloride Solution.

clear solution into an evaporating dish and evaporate the solution as shown in Fig. 53-3.

A white residue remains in the dish. This is magnesium chloride. Again we can write the reaction as an equation.

magnesium + hydrochloric acid →
magnesium chloride + hydrogen

Similarly, if we were to treat magnesium with nitric acid we would get magnesium nitrate. And with acetic acid we would get magnesium acetate.

Are All Metals Active? Magnesium is an active metal. Will other metals react just as readily with hydrochloric acid? This is an important question, and we can answer it by observing an experiment.

Demonstration 53–4. To Show that Metals Vary in Activity.

Place a little of one of the following metals in each of four test tubes: magnesium, zinc, iron, copper. Pour dilute hydrochloric acid into each test tube and observe the effects. Hydrogen is evolved rapidly with magnesium, slowly with iron and zinc, but not at all with copper.

We therefore conclude that iron and zinc are less active than magnesium, and that copper is less active than iron or zinc.

By a similar experiment we can test the activities of other metals and then arrange them in a so-called Activity List.

The Activity List of Metals. If the list is arranged in diminishing order of activity—that is, beginning with the most active and ending with the least active—it is as follows: Potassium, Sodium, Calcium, Magnesium, Aluminum, Zinc, Iron, Lead, Hydrogen, Copper, Mercury, Silver, Platinum, Gold.

This is not a complete list of metals—it includes only the common ones. Notice also that hydrogen is in the list although it is not a metal. But it behaves like a metal and is there for purposes of comparison.

The first important observation to be made about this list is that *metals above hydrogen will displace it from acids; metals below hydrogen will not.* For example, lead will displace hydrogen very slowly. But the metals copper, mercury, silver, platinum and gold are not affected either by sulfuric or hydrochloric acids.

Some Metals React With Water. Another important thing to know is that those metals which liberate hydrogen from acids will also liberate hydrogen from water or steam. Or, *metals above hydrogen in the Activity List will displace hydrogen from water or steam; those below hydrogen will not.*

However, the *rate* at which hydrogen is evolved is considerably slower from water than from acids. For example, zinc does not react with water at all. But hot zinc displaces the hydrogen from steam rapidly.

We will investigate the reaction between the active metal calcium and water.

Demonstration 53–5. Calcium Reacts With Water.

Almost fill a 500 cc beaker with water. Drop a piece of calcium into the water and notice that a reaction starts at once. Place a small funnel or thistle tube over the calcium as shown in Fig. 53-4.

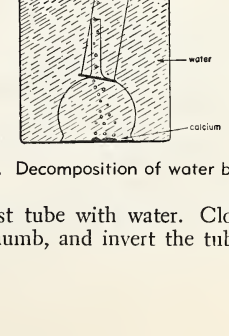


Fig. 53–4. Decomposition of water by calcium.

Fill a test tube with water. Close the tube with the thumb, and invert the tube and place the open end under water. Now arrange the tube so as to collect the bubbles of gas. When the tube is filled with gas, withdraw it from the beaker and place the open end near the flame of a Bunsen burner. The gas burns with a loud pop. This is a test for hydrogen.

Place a piece of red litmus paper in the beaker and notice that it turns blue. The substance in the beaker is neither an acid nor a salt—it is a *base.* Solutions of bases turn red litmus paper blue.

Bases are the third class of compounds to be mentioned—acids, salts and bases. If we wish to give bases a chemical name, we would say they are hydroxides. The base formed in the above reaction is calcium hydroxide. Or,

$$\text{calcium} + \text{water} \rightarrow \\ \text{calcium hydroxide} + \text{hydrogen}$$

Sodium and potassium will also react with water to form hydroxides. But these reactions are dangerous unless done with care. Chemically, they are

$$\text{sodium} + \text{water} \rightarrow \\ \text{sodium hydroxide} + \text{hydrogen}$$

$$\text{potassium} + \text{water} \rightarrow \\ \text{potassium hydroxide} + \text{hydrogen}$$

The metals magnesium, aluminum, zinc, iron, and lead do not react with water at ordinary temperatures. Both metal and water have to be heated before they will react. If steam is passed over the heated metal, the steam is decomposed and hydrogen released. The oxygen from the steam combines with the metal to form an oxide. Or,

$$\text{magnesium} + \text{steam} \rightarrow \\ \text{magnesium oxide} + \text{hydrogen}$$

$$\text{zinc} + \text{steam} \rightarrow \text{zinc oxide} + \text{hydrogen}$$

Notice that at ordinary temperatures a hydroxide is formed, whereas at high temperatures an oxide is formed. These are rather difficult concepts. But they will make sense if we write our equations in symbolized form instead of words. By using symbols we can visualize a reaction more easily than by expressing the reaction in words. In the next chapter we will learn the chemist's shorthand for writing symbols, formulas, and equations.

THINGS TO REMEMBER

Dalton's Atomic Theory states: (1) Matter is composed of indestructible particles called atoms; (2) Atoms of the same element have the same weight and are alike in properties; (3) Atoms of different elements differ in weight and properties from those of other elements; (4) Compounds are formed by the combination of atoms of different kinds.

The Law of Conservation of Mass states, There is no change of weight in any chemical reaction.

The Law of Constant Proportions states, A given compound always contains the same atoms in the same fixed proportion by weight.

An *acid* is a substance which contains hydrogen, this hydrogen being replaceable by a metal to form a salt.

Metals above hydrogen in the *Activity List* will replace hydrogen from acids or water; those below hydrogen will not.

QUESTIONS

A

1. What is a scientific law?

2. What is a scientific theory?

3. Write a short account of the personality of John Dalton.

4. What is meant by the expression, Fellow of the Royal Society?

5. Name three common acids.

6. Name three metals above hydrogen in the Activity List. and three below hydrogen.

7. What is meant by the terms: (*a*) sulfate; (*b*) nitrate; (*c*) base?

B

8. Explain the important differences between the Greek idea of atoms and Dalton's idea.

9. Discuss the reasoning by which Dalton arrived at the Law of Conservation of Mass.

10. Explain how you could verify the law of Constant Proportions.

11. Explain how you could prepare a sample of aluminum chloride using a metal and an acid.

12. Write word equations for the following reactions: (*a*) magnesium + sulfuric acid; (*b*) aluminum + steam; (*c*) calcium + water; (*d*) zinc + hydrochloric acid.

PROJECT

Reaction between Zinc and Copper Sulfate. Pour about 10 cc of copper sulfate solution into a test tube. Place several pieces of zinc in the tube. Close the test tube with a stopper and shake it for some time. Record the two visible changes that take place. How can you explain these changes?

Chapter 54

THE SHORTHAND OF CHEMISTRY

Chemists have found it convenient to represent the elements by symbols. Every element has its own special symbol. Wherever possible, the symbol is the first letter of the word. Thus H is the symbol for hydrogen, O for oxygen, N for nitrogen, S for sulfur, P for phosphorus, U for uranium.

In some cases, more than one element has the same initial letter. A second letter is then necessary to distinguish the element. For example, C stands for carbon, Ca for calcium, Cl for chlorine, and Cr for chromium. Other common symbols with two letters are Al, aluminum; Mg, magnesium; Zn, zinc; Mn, manganese; Br, bromine; Ra, radium.

The metals known to the alchemists acquired different names in different countries. In order to establish common international symbols it was agreed to use their Latin names for this purpose. The following is a list of such elements:

Element	*Latin Name*	*Symbol*
Copper	cuprum	Cu
Gold	aurum	Au
Iron	ferrum	Fe
Lead	plumbum	Pb
Mercury	hydrargyrum	Hg
Potassium	kalium	K
Silver	argentum	Ag
Sodium	natrium	Na
Tin	stannum	Sn

Just as letters can be used to write words, so symbols can be used to represent compounds. If the symbols of different atoms are written together so as to indicate the number of atoms in the molecule of a compound, the result is called a *formula* for the compound. Before we can write formulas, however, we must know something about bonds that bind atoms together.

What is Valence? Some of us may have wondered *why* atoms combine to form compounds. And, once compounds are formed, why do they hold together? It is clear that some kind of "bond" must hold the atoms in place. All atoms that form compounds have bonds. Do different atoms have the same number of bonds? The answer to this question is "No," which means that before we can write the formulas of compounds we must learn the number of bonds of the common atoms.

The number of bonds by which an atom of an element can attach itself to atoms of another element is called the *valence* of the element.

To Write Formulas of Compounds. Let us consider the combination of a hydrogen atom with a chlorine atom to form a molecule of hydrogen chloride. A hydrogen atom has one bond and can be written H—. A chlorine atom also has one bond and can be written —Cl. When these combine, the molecule can be written as H—Cl, or just HCl.

Let us consider the combination of hydrogen and oxygen atoms to form water. The valence of the oxygen atom is 2; in other words, it has two bonds, and can be written O= or —O—. It therefore follows that two hydrogen atoms are needed to combine with one atom of oxygen. Hence the formula for water is H—O—H, or HOH, or, better still H_2O.

Let us now derive the formula for copper oxide. The valence of copper is two so that it can be written as Cu=. Thus the formula for the oxide is Cu=O, or CuO. Notice that while we need the valence bonds to derive a formula, the bonds are not written in the formula itself. Notice also that there are no free bonds in a compound. Free bonds would mean that the substance is active and unstable—it would instantly combine with something to tie up the free bond. Hence we conclude that the formulas for the following compounds are

Hydrogen Chloride	HCl
Water	H_2O
Copper Oxide	CuO

The Table of Valences. What are the formulas for sodium oxide and aluminum sulfide? Before we can write the formulas we must know the valences of the elements. Sodium has a valence of one, and aluminum a valence of three. Some elements have a valence of four and others of five. It is convenient to tabulate them according to valence. An element with a valence of one is a *monovalent* element; an element with a valence of two is *divalent*. If its valence is three it is *trivalent*; if four, *tetravalent*; if five, *pentavalent*.

A list of the valences of some of the common elements is as follows:

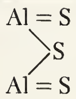
Valence	
One (mono-)	Hydrogen (H), Chlorine (Cl), Bromine (Br), Potassium (K), Sodium (Na), Silver (Ag).
Two (di-)	Oxygen (O), Sulfur (S), Copper (Cu), Lead (Pb), Magnesium (Mg), Iron (Fe,) Zinc (Zn), Mercury (Hg), Calcium (Ca), Manganese (Mn), Tin (Sn).
Three (tri-)	Aluminum (Al), Nitrogen (N).
Four (tetra-)	Carbon (C), Silicon (Si).
Five (penta-)	Phosphorus (P).

Formulas of Binary Compounds. Binary compounds are made up of *two* elements. All their names end in *-ide*. For example, a chloride contains chlorine and another element; sulfide contains sulfur and another element; a nitride contains nitrogen and another element.

The Formula for Sodium Oxide. Sodium has a valence of one, Na—, and oxygen a valence of two, —O—. Therefore, the formula is Na—O—Na, or Na_2O.

The Formula for Aluminum Sulfide. The valences are Al≡ and S=. The smallest number of bonds needed to bind these elements together is six. This means 2 atoms of aluminum and 3 atoms of sulfur are needed. Or, Al_2S_3.

Another way of writing the formula would be to put in the bonds. Thus



Notice again that there are no free bonds in a stable compound.

The Formula for Calcium Nitride. The valence bonds are Ca=, and N≡. $Ca{=}\underset{\diagup}{N}$ is clearly not a stable compound. Why not? Three atoms of calcium have six bonds, and two atoms of nitrogen also have six bonds. Therefore, the formula is Ca_3N_2.

Other formulas are

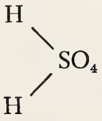
Ferrous oxide	FeO
Zinc bromide	$ZnBr_2$
Silver sulfide	Ag_2S

QUESTIONS

1. Write formulas for: (*a*) potassium oxide; (*b*) manganese chloride; (*c*) sodium sulfide; (*d*) lead bromide; (*e*) copper nitride.
2. Write formulas for: (*a*) phosphorus oxide; (*b*) tin chloride; (*c*) silver nitride; (*d*) mercury oxide; (*e*) calcium oxide.
3. Write formulas for: (*a*) ferrous oxide; (*b*) tin nitride; (*c*) carbon chloride; (*d*) calcium chloride; (*e*) aluminum bromide.

Valences of Radicals. In the previous chapter we referred to acids such as sulfuric and nitric acids, and on page 260, to carbonic acid. All these acids contain hydrogen and the other parts of their molecules are radicals. What are radicals? *A radical is a group of elements in a compound which is not usually decomposed in a chemical reaction.* Sulfuric acid contains a sulfate radical, SO_4; nitric acid contains a nitrate radical, NO_3; carbonic acid contains a carbonate radical, CO_3. Radicals cannot exist by themselves. They have free bonds that make them very active. In the above acids, for example, all the radicals are attached to hydrogen.

The sulfate radical has two free bonds, $> SO_4$, or as we usually say, its valence is two. The sulfate radical can therefore attach itself to two hydrogen atoms in forming sulfuric acid. The formula for this acid is



or, H_2SO_4.

A nitrate radical has a valence of one so that the formula for nitric acid is HNO_3. The carbonate radical has a valence of two so that the formula for carbonic acid is H_2CO_3.

When zinc reacts with sulfuric acid, as described on page 472, the two hydrogen atoms are replaced by a zinc atom to form a molecule of zinc sulfate, $Zn{=}SO_4$, or $ZnSO_4$.

At this point one might ask, Why is the acid called sulfuric acid? And why is the salt called zinc sulfate?

Naming Acids and Salts. An acid that contains *two* elements is called a *binary* acid; one that contains *three* elements is called a *ternary* acid.

The name of a binary acid includes the names of both elements in the acid and ends in *-ic*. For example, Hydrochloric acid (HCl) contains hydrogen and chlorine; Hydrobromic acid (HBr) contains hydrogen and bromine; Hydrosulfuric acid (H_2S) contains hydrogen and sulfur.

The names of salts of binary acids end in *-ide*. For example,

Acid	*Salt*
HCl	Sodium chloride ($NaCl$)
HBr	Sodium bromide ($NaBr$)
H_2S	Sodium sulfide (Na_2S)

Ternary Acids. Ternary acids are named after the element, other than hydrogen or oxygen, which they contain. Their names usually end in *-ic*, the same as binary acids. A few examples of common ternary acids are

Sulfuric acid	H_2SO_4
Phosphoric acid	H_3PO_4
Carbonic acid	H_2CO_3
Nitric acid	HNO_3

The names of the salts of ternary *-ic* acids, end in *-ate*. For example,

Acid	*Salt*
H_2SO_4	Sodium sulfate (Na_2SO_4
H_3PO_4	Sodium phosphate (Na_3PO_4)
H_2CO_3	Sodium carbonate (Na_2CO_3)
HNO_3	Sodium nitrate ($NaNO_3$)

From the above examples, it is clear that the valence of the nitrate radical is one, the valence of the carbonate radical is two, and of the phosphate radical three. The valences of some of the common radicals are summarized below. They should be memorized.

Radical	*Formula*	*Valence*
Phosphate	PO_4	3
Sulfate	SO_4	2
Carbonate	CO_3	2
Nitrate	NO_3	1
Hydroxide	OH	1
Ammonium	NH_4	1

The list of compounds can now be extended by combining any metal (or the ammonium radical which acts like a metal) with any one of the radicals.

Formula for Lead Nitrate. The valence of lead is two ($Pb=$), and that of the nitrate radical is one ($-NO_3$). Therefore, two nitrate radicals are needed per molecule and the formula is $Pb(NO_3)_2$.

Notice that if there is more than one radical in the molecule it must be enclosed in brackets. The subscript 2 indicates the number of radicals in the molecule.

Formula for Ammonium Carbonate. The valence of the ammonium radical is one, and that of the carbonate radical is two. Therefore two ammonium radicals are needed and the formula is $(NH_4)_2CO_3$.

Formula for Magnesium Phosphate. The valence of magnesium is two, and that of the phosphate radical is three. Hence *six* bonds are necessary to link them together. Therefore three atoms of magnesium and two phosphate radicals are required. Therefore the formula is $Mg_3(PO_4)_2$.

The following are additional examples which include radicals:

Silver sulfate	Ag_2SO_4
Calcium hydroxide	$Ca(OH)_2$
Tin nitrate	$Sn(NO_3)_2$
Sodium phosphate	Na_3PO_4

Formulas for Gas Molecules that are Elements. A number of elements are gases at ordinary temperatures. Examples of such elements are hydrogen, oxygen, nitrogen, chlorine. In all such cases, a molecule consists of 2 atoms.

Thus the symbol for oxygen is O, but the formula of an oxygen molecule is O_2. Notice the subscript 2 indicates the number of atoms per molecule.

The number of molecules is always placed in front of the symbol. Thus $7O_2$ means 7 molecules of oxygen, and $7H_2SO_4$ means 7 molecules of sulfuric acid.

QUESTIONS

1. (*a*) How many oxygen atoms are there in the molecule $Al_2(SO_4)_3$?

(*b*) What is the total number of atoms in this molecule?

2. Fill in the blanks with the proper formula as shown in the first row. The valence is placed above each atom or radical.

	1 OH	2 CO_3	3 PO_4	2 SO_4	1 NO_3
1 K	KOH	K_2CO_3	K_3PO_4	K_2SO_4	KNO_3
1 Ag					
2 Mg					
3 Al					

3. Write formulas for: (*a*) calcium nitrate; (*b*) ammonium sulfate; (*c*) ammonium sulfide; (*d*) sodium nitrate; (*e*) sodium nitride.

4. Write formulas for: (*a*) ammonium hydroxide; (*b*) ferrous hydroxide; (*c*) manganese nitrate; (*d*) aluminum nitrate; (*e*) mercury phosphate.

5. Write formulas for: (*a*) zinc nitride; (*b*) zinc hydroxide; (*c*) lead carbonate; (*d*) lead carbide; (*e*) tin bromide.

6. Write formulas for: (*a*) hydrogen oxide; (*b*) aluminum carbonate; (*c*) magnesium nitrate; (*d*) sodium hydroxide; (*e*) silver chloride.
7. Write the formulas for: (*a*) ten molecules of hydrogen; (*b*) two molecules of chlorine; (*c*) five molecules of sodium phosphate; (*d*) three molecules of nitrogen; (*e*) two hundred molecules of copper sulfate.
8. State the total number of atoms in 10 molecules of calcium phosphate.

What are Equations? A symbolized equation gives a picture of a chemical reaction in concise form. The formulas on the left hand side show the substances at the beginning of a reaction, or the *reactants;* the formulas on the right hand side show the substances formed by the reaction, or the *products.* Reactants and products are usually connected by an arrow (→).

An equation is said to be balanced when there are the same number and kind of atoms on either side. This is in accordance with the Law of Conservation of Mass. That is, since nothing is created or destroyed in a chemical change, the total number of atoms and their total weight must remain unchanged.

Consider the reaction,

zinc + sulfuric acid → zinc sulfate + hydrogen

The symbolized equation for this reaction is

$$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$$

When expressed in this form it is clear that the zinc has replaced the hydrogen of the acid.

To Balance Equations. Equations are often more complicated than the example above. In order to write a balanced equation, four conditions must be borne in mind:

(1) State the experimental fact accurately.
(2) Write the reactants on the left of the arrow and the products on the right of it.
(3) Write the correct formulas of all reactants and products.
(4) Balance the equation; that is, make the total number of atoms on the left of the arrow equal to the total number on the right of it, using the smallest possible balancing numbers.

We can illustrate these points by writing the equation for the burning of phosphorus, a reaction in which phosphoric oxide is formed (See page 207).

The first step is to state the experimental facts. Or,

$$P + O_2 \rightarrow P_2O_5$$

This "equation" is not balanced since there are two atoms of oxygen on the left hand side, and five atoms of oxygen on the right. To convert groups of two into groups of five, requires 10 atoms of oxygen. Ten oxygen atoms form five molecules of oxygen. Ten oxygen atoms also supply the oxygen content of two molecules of phosphoric oxide.

Therefore the next step is to write

$$P + 5O_2 \rightarrow 2P_2O_5$$

The oxygen atoms are now balanced but not the phosphorus atoms. There are four atoms of phosphorus on the right but only one on the left. Hence the number four must be placed before the phosphorus symbol on the left. Or,

$$4P + 5O_2 \rightarrow 2P_2O_5$$

This is a balanced equation.

We can now write equations for some of the reactions referred to in earlier chapters. The reaction between magnesium and hydrochloric acid discussed on page 472 is

$$Mg + 2HCl \rightarrow MgCl_2 + H_2$$

Metals and Water. As explained on page 473, calcium and sodium react with water to form hydrogen and hydroxides. Or,

$$Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$$
$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$

Hot magnesium reacts with steam to form hydrogen and magnesium oxide (see page 474). Or,

$$Mg + H_2O \rightarrow MgO + H_2$$

Equations of Other Reactions. *Burning of Methane.* Methane (CH_4), a constituent of natural gas, burns to give a hot flame (see page 253). The reaction is

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

If methane (or fire-damp) explodes in a coal mine, carbon monoxide, instead of carbon dioxide, is formed because there is not enough oxygen for complete oxidation (see page 217). The equation for this reaction is

$$2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$$

Preparation of Carbon Dioxide. Carbon dioxide is prepared by the reaction of hydrochloric acid upon marble or calcium carbonate (see page 226). The equation for the reaction is

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$$

Burning of Gasoline. One of the constituents of gasoline is C_6H_{14}. It burns to give carbon dioxide and water vapor (see page 218). The equation for the reaction is

$$2C_6H_{14} + 19O_2 \rightarrow 12CO_2 + 14H_2O$$

This is a difficult equation to balance.

QUESTIONS

1. Write word and symbolized equations to show the burning of: (*a*) carbon; (*b*) sulfur.
2. Write balanced equations for the following reactions: (*a*) Zinc and hydrochloric acid; (*b*) Iron and sulfuric acid; (*c*) Hot aluminum and steam; (*d*) Potassium and water.
3. Write a balanced equation for the burning of hydrogen. Explain the meaning of all the symbols and numbers in the equation.
4. Ethane (C_2H_6) is a constituent of natural gas. Write the equation to show the burning of ethane.
5. In the preparation of acetylene, water is dropped on to calcium carbide (see page 257). The products are calcium hydroxide and acetylene. Write a balanced equation for the reaction.

Symbolized Equations for Word Equations. Facility in the use of the valence table can be gained by transcribing word equations into symbolized equations. For example,

(1) silver sulfate + ammonium chloride → ammonium sulfate + silver chloride.

Expressed in symbolized form the equation is

$$Ag_2SO_4 + 2NH_4Cl \rightarrow (NH_4)_2SO_4 + 2AgCl$$

(2) calcium chloride + potassium phosphate → calcium phosphate + potassium chloride

becomes

$$3CaCl_2 + 2K_3PO_4 \rightarrow Ca_3(PO_4)_2 + 6KCl$$

The Meaning of an Equation. A balanced equation gives us a good deal of valuable information. For instance it shows

(1) The reactants and products of a reaction;
(2) The composition of the molecules which react;
(3) The number of each kind of molecule taking part in the reaction.

On the other hand, we must realize the limitations of an equation. An equation is no assurance that the substances actually do react. This we must know from our chemical experience. It is possible to write a large number of balanced equations for reactions that do not take place at all. For example,

$$Cu + H_2SO_4 \rightarrow CuSo_4 + H_2$$

is a balanced equation and yet we know by referring to the Activity List that copper does not displace hydrogen in an acid.

Then again an equation does not tell us anything about the conditions that have to be imposed before the reaction will take place. Do the substances have to be heated? Do the substances have to be in solution? Is the speed of the reaction slow or rapid? Questions of this kind cannot be answered by examining equations.

A study of a number of equations, however, indicates that chemical reactions can be classified into three main types. A glance at an equation shows immediately which type of reaction the equation represents.

Three Types of Chemical Reactions. Chemical reactions are usually classified into the following types:

(a) combination, (b) replacement,
(c) decomposition.

Combination. As the name implies, this type is a simple combination of substances. It is illustrated by such reactions as

$$Fe + S \rightarrow FeS$$
$$S + O_2 \rightarrow SO_2$$

Replacement. This type of reaction refers to the replacement of one substance by another. For example,

$$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$$
$$Mg + H_2O \rightarrow MgO + H_2$$

In both these examples the metal replaces hydrogen.

Decomposition. This term refers to the decomposition of a single substance. You may recall that Lavoisier decomposed mercury oxide by heating it. Or,

$$2HgO \rightarrow 2Hg + O_2$$

This is a decomposition reaction.

QUESTIONS

1. State three facts that a balanced equation indicates.
2. State three facts or conditions about a reaction that an equation does not indicate.
3. Name the different types of chemical reactions and give an example of each.
4. Write balanced equations for:
   (*a*) aluminum sulfate + calcium hydroxide → aluminum hydroxide + calcium sulfate.
   (*b*) silver nitrate + sodium chloride → silver chloride + sodium nitrate.
   (*c*) magnesium chloride + phosphoric acid → magnesium phosphate + hydrochloric acid.
   (*d*) ferrous chloride + sodium hydroxide → ferrous hydroxide + sodium chloride.
   (*e*) tin + oxygen → tin oxide.
5. Write balanced equations for:
   (*a*) sodium carbonate + copper sulfate → sodium sulfate + copper carbonate.
   (*b*) ammonium phosphate + calcium chloride → ammonium chloride + calcium phosphate.
   (*c*) aluminum nitrate + potassium hydroxide → aluminum hydroxide + potassium nitrate.
   (*d*) manganese sulfate + ammonium hydroxide → manganese hydroxide + ammonium sulfate.
   (*e*) mercury sulfate + lead nitrate → mercury nitrate + lead sulfate.

THINGS TO REMEMBER

A *symbol* is a letter, or a combination of two letters, that stands for an element.

A *formula* is a group of symbols that represents a compound.

The *valence* of an element is the number of bonds by which the element can attach itself to other elements.

A *binary* compound is made up of two elements.

The names of binary compounds end in *-ide.*

A *radical* is a group of elements in a compound that is not usually decomposed in a chemical reaction.

A *ternary* acid contains three elements.

The names of the salts of ternary *-ic* acids end in *-ate.*

An equation is *balanced* when the total number of atoms representing the reactants equals the total number of atoms representing the products.

The three *types of chemical reactions* are (*a*) combination, (*b*) replacement (*c*) decomposition.

PROJECT

Refer to a book on historical chemistry and write out a list of chemical symbols used by John Dalton. Dalton's symbols were unsatisfactory and were not accepted by chemists. Explain why.

Chapter 55

WHAT ARE IONS?

In Chapter 3 it was stated that atoms are electrical in nature—they consist of a positively charged nucleus with enough electrons outside the nucleus to make the atom electrically neutral. Let us consider what happens when atoms combine to form molecules or crystals. Why does a crystal of sodium chloride stay together? What is the nature of the bond that holds the sodium and chlorine atoms in place? It is clear that if the chlorine atoms were negatively charged and the sodium atoms positively charged they would be bound together by an electrostatic force of attraction. How can atoms become electrically charged?

You may recall that an object becomes negatively charged if it gains electrons, and it becomes positively charged if it loses electrons (see page 23). The same is true of atoms. An atom that loses an electron becomes positively charged; an atom that gains an electron becomes negatively charged. When atoms gain or lose electrons, they are changed to *ions*. In other words, *an ion is an atom that has an excess of, or a shortage of, one or more electrons.*

Why do Molecules hold together? If a sodium atom loses an electron (symbol, e) it becomes a sodium ion with a positive charge. If a chlorine atom gains an electron, it becomes a chloride ion with a negative charge. These changes can be expressed in symbols as follows,

$$\begin{array}{ccc} \text{Na} & -\,e \rightarrow & \text{Na}^+ \\ \text{Sodium atom} & & \text{Sodium ion} \\ \text{Cl} & +\,e \rightarrow & \text{Cl}^- \\ \text{Chlorine atom} & & \text{Chloride ion} \end{array}$$

The loss and gain of electrons is what causes chemical changes to take place.

If a small piece of metallic sodium is dropped into a bottle of chlorine a chemical change takes place and sodium chloride is formed. Or,

$$2Na + Cl_2 \rightarrow 2NaCl$$

This reaction takes place because every sodium atom gives up one of its electrons to a chlorine atom. The sodium and chloride ions, formed in this way, are oppositely charged and therefore attract each other. It

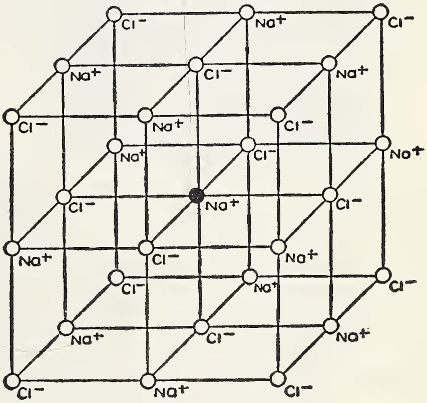


Fig. 55–1. Ions in crystalline sodium chloride.

is the electrostatic force of attraction that holds molecules or crystals together. In other words, a crystal of sodium chloride does not contain any atoms at all, but only ions. Fig. 55–1 shows how these ions are arranged into a pattern or lattice. Notice that every sodium ion is surrounded by chloride ions, and every chloride ion is surrounded by sodium ions. Now do you understand why a grain or a crystal of sodium chloride remains intact?

What does the term Valence mean? Let us return to the reaction between sodium and chlorine.

$$\mathrm{Na} - e \rightarrow \mathrm{Na}^+$$
$$\mathrm{Cl} + e \rightarrow \mathrm{Cl}^-$$

Since the sodium ion is positively charged, it is said to have a positive valence; since the chloride ion is negatively charged, it is said to have a negative valence. Moreover, *the valence of an ion is equal to its charge.* Therefore the valence of Na^+ is $+1$, and the valence of Cl^- is -1.

Let us now consider a molecule of sodium sulfide, Na_2S. Here each sodium atom loses an electron, and the sulfur atom gains two electrons to form the sulfide ion, $S^=$. Or,

$$2\mathrm{Na} - 2e \rightarrow 2\mathrm{Na}^+$$
$$\mathrm{S} + 2e \rightarrow \mathrm{S}^= \text{ or } \mathrm{S}^{-2}$$

The valence of the sulfide ion is -2.

Or, again, a molecule of copper chloride, $CuCl_2$, is formed by the gain of an electron by each of two chlorine atoms, and the loss of two electrons by a copper atom. Or,

$$\mathrm{Cu} - 2e \rightarrow \mathrm{Cu}^{++} \text{ or } \mathrm{Cu}^{+2}$$
$$2\mathrm{Cl} + 2e \rightarrow 2\mathrm{Cl}^-$$

Therefore, the valence of the copper ion is $+2$.

Actually we can say that the valences of atoms are the same as the valences of their ions. Or,

valence of Na is $+1$ valence of Cl is -1
valence of Cu is $+2$ valence of S is -2

Notice that this concept of valence is somewhat different from that given in Chapter 54. As soon as we consider gain or loss of electrons, valences become positive or negative. The valence numbers are the same as those given in the table on page 477. But *metals usually have a positive valence, and non-metals usually have a negative valence.*

Why does a Salt Solution conduct a Current? Let us return to sodium chloride and make further investigations concerning its ionic properties. The passage of an electric current will give some useful information.

Demonstration 55–1. To Show that a Current Flows Through a Salt Solution.

Arrange the apparatus as shown in Fig. 55–2. Place some powdered sodium chloride in the beaker and dip the two short stout copper wires into it. The copper wires are the terminals of a circuit with a 25-watt bulb and a switch in series. The town current supplied at about 110 volts (alternating or direct) is satisfactory for this purpose.

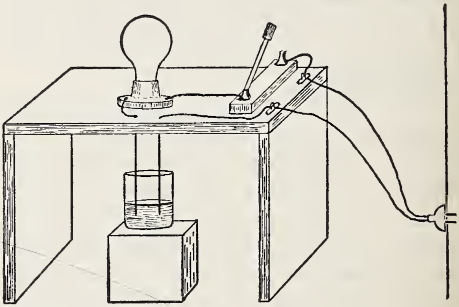


Fig. 55–2. Apparatus to show conductivity of solutions.

Fit the plug into the socket and close the switch. The bulb does not glow so that no current flows.

Now pour water into the beaker. Instantly the bulb lights up.

The two questions that now come to mind are, Why does the current flow? Why does water make the salt a conductor? The water molecules attract the sodium and chloride ions more strongly than they attract each other. As a result, the ionic lattice breaks down and the ions are able to move about freely. The ions are attracted to the copper terminals and, by doing so, they conduct the current. In other words, the conductivity of a solution is due to the movement of its ions. It follows that if a solution conducts a current, there must be ions in the solution.

Demonstration 55–2. Do all Solutions Conduct Electricity?

Prepare solutions of potassium nitrate, sodium hydroxide, hydrochloric acid, sugar, and alcohol. Pour each solution in turn into the beaker and test it for conductivity. The bulb lights up brightly when solutions of acid, base, and salt are in the beaker, but not at all with the sugar and alcohol solutions.

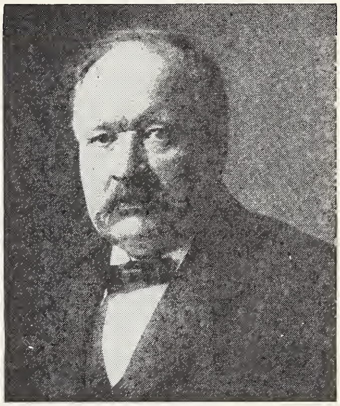
The important conclusion to be drawn from this experiment is that solutions of acids, bases and salts conduct a current whereas solutions of other substances do not. This difference enables us to divide chemical compounds into two classes, *electrolytes* and *non-electrolytes*. Electrolytes are substances whose solutions conduct electricity; all other substances are non-electrolytes. *Acids, bases and salts are electrolytes.*

The Theory of Ionization. The first man to investigate the conductivity of electrolytes was a Swedish chemist named Arrhenius. He argued that if solutions conduct electricity their molecules must be decomposed into electrically charged particles. These charged particles he called *ions*, a Greek word meaning *going*. This is a descriptive word because Arrhenius believed that these charged particles actually moved when the current flowed, the positively charged particles moving in one direction and the negatively charged ones in the opposite direction.

Arrhenius summarized his views in three statements which were known as the Ionization Theory and were first published in 1887:

1. *Molecules of electrolytes dissociate in water solution to form electrically charged particles or ions.*
2. *Both positive and negative ions are formed by this dissociation.*
3. *The total number of positive charges equals the total number of negative charges.*

The Theory of Ionization opened up an entirely new chemical field and it has been responsible for some startling advances in atomic studies during the past fifty years.



Courtesy The Edgar Fahs Smith Memorial Collection

Fig. 55–3. Svante Arrhenius (1859-1927).

The Ionization of Acids. Arrhenius stated that acids are ionized by adding water to them. Moreover, he said, the greater the amount of water added, the greater is the extent of ionization. Thus, pure liquid hydrogen chloride does not conduct a current. Therefore it contains no ions. If water is added, hydrochloric acid is formed which conducts a current. Therefore hydrochloric acid contains ions. This change can be shown as

$$HCl \rightleftarrows H^+ + Cl^-$$

Notice that he represented the change as a reversible reaction between molecules and ions. The oppositely charged ions combine to form molecules, and the molecules dissociate into ions. In other words, hydrochloric acid is a mixture of hydrochloric acid molecules, hydrogen ions, and chloride ions.

Similarly, dilute sulfuric acid contains hydrogen ions and sulfate ions. Or,

$$H_2SO_4 \rightleftarrows 2H^+ + SO_4^=$$

Dilute nitric acid contains hydrogen ions and nitrate ions. Or,

$$HNO_3 \rightleftarrows H^+ + NO_3^-$$

And acetic acid contains hydrogen ions and acetate ions. Or,

$$CH_3COOH \rightleftarrows H^+ + CH_3COO^-$$

It is clear from the above reactions that all acids contain hydrogen ions. Indeed, *acids can be defined as substances which react with water to form hydrogen ions.* This definition is preferable to that given on page 472.

Properties Common to All Acids. Aqueous solutions of all acids have certain properties in common. These common "acid" properties, which are listed below, must therefore also be properties of hydrogen ions.

1. *Acids have a sour taste.*
   We are familiar with the sour taste of lemon juice, which contains citric acid, and the sour taste of vinegar, which contains acetic acid.
2. *Acids turn blue litmus paper red.*
3. *Acids react with active metals to give hydrogen.*
   We have already discussed a number of reactions of this type in the previous chapter. Let us again consider the reaction between zinc and dilute sulfuric acid,

   $$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$$

   As an *ionic equation* the reaction can be written,

   $$Zn + 2H^+ + SO_4^= \rightarrow Zn^{++} + SO_4^= + H_2$$

In this form the equation shows that the reaction takes place between zinc metal and hydrogen ions. The sulfate ions take no part in the reaction and can therefore be omitted from the equation. Or,

$$Zn + 2H^+ \rightarrow Zn^{++} + H_2$$

We now know that the reaction is due to an exchange of electrons, the zinc atom losing two electrons, and the two hydrogen ions gaining two electrons. Or,

$$Zn - 2e \rightarrow Zn^{++}$$
$$2H^+ + 2e \rightarrow H_2$$

Strong and Weak Acids. Some acids conduct a current more easily than others. This is because some acids contain a greater percentage of hydrogen ions than others. We usually express this by saying that some acids are *strong* and others are *weak*. *A strong acid is highly ionized; a weak acid is not highly ionized.* Hydrochloric, sulfuric, and nitric acids are strong; acetic and carbonic acids are weak. A comparison of the strength of acids can easily be shown by a conductivity experiment.

Demonstration 55–3. Strong Acids are Good Conductors; Weak Acids are Poor Conductors.

Rig up the conductivity apparatus and compare the brightness of the light when the copper terminals are dipped into dilute sulfuric acid and dilute acetic acid. The light is much brighter in the case of sulfuric acid.

The brightness of the light is a measure of the amount of current flowing through the lamp. And this is in turn determined by the number of ions in solution. We therefore conclude that sulfuric acid is more highly ionized than acetic acid.

The Chemical Activity of Acids. The chemical activity of acids depends upon the concentration of the hydrogen ions—the higher the concentration, the greater the activity. We could therefore predict that a more vigorous reaction takes place between zinc and hydrochloric acid than between zinc and acetic acid. This prediction can be confirmed by experiment.

Demonstration 55–4. To Show that Zinc Reacts More Readily with Dilute Hydrochloric Acid than Dilute Acetic Acid.

Place a piece of zinc in each of two test tubes. Pour 10 cc of dilute acetic acid into one test tube and 10 cc of dilute hydrochloric acid into the other. Notice that hydrogen is evolved slowly in one case and rapidly in the other. How can you explain this difference in activity?

The Ionization of Bases. Arrhenius stated that sodium hydroxide ionizes in aqueous solution to give sodium and hydroxide ions (OH^-). Or,

$$NaOH \rightleftharpoons Na^+ + OH^-$$

Similarly, potassium hydroxide and ammonium hydroxide also ionize,

$$KOH \rightleftharpoons K^+ + OH^-$$
$$NH_4OH \rightleftharpoons NH_4^+ + OH^-$$

It is obvious from the above reactions that all bases contain hydroxide ions. We can therefore define *a base as a substance which in water solution forms hydroxide ions.*

Properties Common to All Bases. Aqueous solutions of all bases have certain properties in common. These are properties of hydroxide ions.

1. *Bases have a bitter taste.*
2. *Bases turn red litmus paper blue.*
3. *Bases react with acids to form salts and water.*

The reaction with acids is exceedingly important since it is a method by which salts can be made. Since, in this type of reaction, acids are neutralized by bases, the term *neutralization* is applied to it. Expressed as a word equation, a neutralization reaction is

acid + base → salt + water

Neutralization of an acid by a base. Suppose we add just enough hydrochloric acid to sodium hydroxide to neutralize it. The reaction is

$$HCl + NaOH \rightarrow NaCl + H_2O$$

The salt, sodium chloride, is neither basic nor acidic—it is neutral.

Written in ionic form the reaction is:

$$H^+ + Cl^- + Na^+ + OH^- \rightarrow Na^+ + Cl^- + H_2O$$

There are two things to notice about this reaction. First, water does not ionize to any marked degree so that ions are not included in the formula for water. Next, since the product contains neither hydrogen nor hydroxide ions it is neutral.

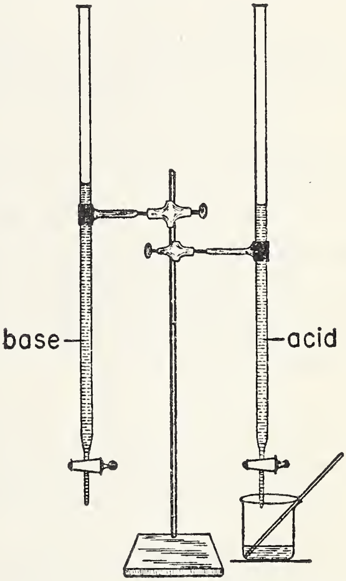


Fig. 55–4. Burettes illustrating neutralization.

We have assumed that this reaction is stopped at the right point. If too much acid is added, the product will be acidic. If too much base is added, the product will be basic. How can we tell when we have reached the "end point"? Or, in other words, how can we avoid an excess of acid or base? We need an "indicator" for this purpose, and a convenient indicator is litmus.

Demonstration 55–5. To Neutralize an Acid by a Base.

Pour 20 cc of dilute hydrochloric acid and 20 cc of dilute sodium hydroxide into a beaker. Stir the mixture with a glass rod. Extract one drop of the mixture on the end of a glass rod and touch a piece of red litmus paper with it. Extract another drop but this time touch a piece of blue litmus paper. The change in color indicates whether the solution is basic or acidic. Let us assume it is basic.

Add hydrochloric acid, a drop at a time, from a glass tube, until the solution is neither acidic nor basic to litmus. The end point has then been reached.

Taste the solution and notice the salty flavor.

Pour about half the solution in an evaporating dish. Evaporate the solution to dryness. Taste the residue to prove it is nothing but common salt.

Let us again write the ionic equation for this reaction,

$$H^+ + Cl^- + Na^+ + OH^- \rightarrow Na^+ + Cl^- + H_2O$$

Notice that sodium and chloride ions appear on both sides of the equations. We therefore conclude they take no part in the reaction and can be left out. The equation then becomes

$$H^+ + OH^- \rightarrow H_2O$$

In other words, this type of reaction is really a combination of the hydrogen ions of the acid with the hydroxide ions of the base to form water. And this is true whatever the acid or base.

Suppose sulfuric acid is neutralized by potassium hydroxide. The equation for the reaction is

$$H_2SO_4 + 2KOH \rightarrow K_2SO_4 + 2H_2O$$

The ionic equation is

$$2H^+ + SO_4^= + 2K^+ + 2OH^- \rightarrow$$
$$2K^+ + SO_4^= + 2H_2O$$

And the simplest ionic equation is

$$H^+ + OH^- \rightarrow H_2O$$

Strong and Weak Bases. As in the case of acids, some bases are strong and others are weak. Both sodium hydroxide and potassium hydroxide are strong bases. Ammonium hydroxide is a weak base. It is important to recognize this difference and it may be well to test it by experiment.

Demonstration 55–6. To Show Sodium Hydroxide is a Strong Base and Ammonium Hydroxide is a Weak Base.

Dip the copper terminals of the conductivity apparatus first into dilute ammonium hydroxide and then into dilute sodium hydroxide. The lamp glows much brighter when sodium hydroxide is used. We therefore conclude that sodium hydroxide is more highly ionized than ammonium hydroxide.

ELECTROLYSIS

In the above conductivity experiments an alternating current has been used. If a direct current is used instead, the ions travel to the electrodes (anode and cathode) where a chemical action takes place. As a result, the electrolyte is decomposed. The decomposition of an electrolyte by a current is called *electrolysis.*

Electrolysis is an important operation in many chemical industries. For instance, electroplating depends on electrolysis. On page 449 we discussed the electroplating of copper in the refining process. Chrome plating on an automobile and silver plating of cutlery are also industrial applications of this process. Let us return to the copper plating experiment and consider it in the light of the ionization theory.

Copper Plating. The electrolyte is copper sulfate which ionizes as follows,

$$CuSO_4 \rightarrow Cu^{++} + SO_4^=$$

Figure 50–5 on page 450 shows a solution of copper sulfate in a jar. The anode is made of pure copper, and the cathode is an article to be plated. An ionic diagram of this arrangement is shown in Fig. 55–5.

The anode is charged positive by the battery and the cathode is charged negative. The copper ions are therefore attracted to the cathode and the sulfate ions are attracted to the anode. Why? It is important to notice that when the current flows, ions move in opposite directions in the electrolyte—positive ions to the cathode, and negative ions to the anode. What happens at the electrodes?

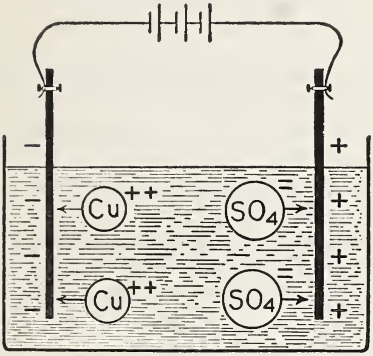


Fig. 55-5. Ionic diagram for copper plating.

Reaction at the Cathode. The cathode is negatively charged; that is, it is supplied with electrons by the battery. Copper ions can therefore pick up electrons from the cathode and the following reaction takes place,

$$Cu^{++} + 2e \rightarrow Cu$$

In this reaction, copper ions are changed to copper atoms so that metallic copper is plated on the cathode. If this process continues, the copper ions would eventually be removed from solution, and the action stopped, unless the ions can in some way be replenished.

Reaction at the Anode. At the anode copper atoms lose electrons to form copper ions. Or,

$$Cu - 2e \rightarrow Cu^{++}$$

In this way the solution is replenished with copper ions.

The result of these two reactions is that copper is transferred from the anode to the cathode. As stated above, the cathode can be a suitable article of any shape. When it is removed from the electrolytic bath it is plated with an even shiny coat of red copper.

If we wish to plate an article with silver the procedure is the same. It would, however, be necessary to use a silver salt as an electrolyte and a rod of pure silver as the anode.

THINGS TO REMEMBER

An *ion* is an atom that has an excess of, or a shortage of, electrons.

If an atom gains an electron it forms a *negatively charged ion;* if it loses an electron it forms a *positively charged ion.*

The *valence of an ion* is equal to the charge upon it.

Metals usually have a *positive valence;* nonmetals a *negative valence.*

Electrolytes are substances whose solutions conduct electricity.

Acids, bases, and *salts* are electrolytes.

The Arrhenius *Theory of Ionization* states:

1. Molecules of electrolytes dissociate in water solution to form positive and negative ions.
2. The total number of positive charges equals the total number of negative charges.

Acids are substances that react with water to form hydrogen ions.

A *strong acid* is one that is highly ionized; a *weak acid* is not.

Bases are substances that react with water to form hydroxide ions.

Electrolysis is the decomposition of an electrolyte by an electric current.

QUESTIONS

A

1. An atom becomes a negatively charged ion if it gains one or more electrons. Explain why.
2. State the valences of the following atoms: (*a*) hydrogen; (*b*) zinc; (*c*) chlorine; (*d*) sulfur. Give your reason for each selection.
3. Give an example of a solution that conducts a current and one that does not. Account for the conductivity of the selected solution.
4. Name four electrolytes.
5. State three properties of hydrogen ions.
6. Name a strong acid and a strong base, also a weak acid and a weak base.
7. State three properties of hydroxide ions.

B

8. Explain the gain and loss of electrons when the metal sodium combines with chlorine gas.
9. Explain what happens to the ions when a direct current causes the electrolysis of hydrochloric acid.
10. (*a*) Write an equation to show the ionization of dilute sulfuric acid.
    (*b*) Show that the number of positive charges equals the number of negative charges.
    (*c*) Does the number of positive ions equal the number of negative ions? Explain.
11. (*a*) Write the ionic equation for the reaction between magnesium and dilute sulfuric acid.
    (*b*) Show the electron transfer that takes place.
12. (*a*) Explain what is meant by the term *neutralization.*
    (*b*) Write the simplest ionic equation for a neutralization reaction.
13. Explain the process of copper plating.

PROJECT

Neutralization of Barium Hydroxide by Sulfuric Acid. Barium Hydroxide solution reacts with dilute sulfuric acid according to the equation

$$Ba(OH)_2 + H_2SO_4 \rightarrow BaSO_4 + 2H_2O$$

Barium sulfate is insoluble—it forms a white precipitate. Therefore it does not ionize. An ionic equation for this reaction is

$$Ba^{++} + 2OH^- + 2H^+ + SO_4^= \rightarrow BaSO_4 + H_2O$$

Since no ions are present at the end point the solution will not conduct a current. Therefore the end point can be indicated by two devices: (1) a chemical indicator; (2) a light bulb.

A suitable indicator is phenol phthalein dissolved in alcohol. This indicator is red in alkaline solution and colorless in neutral or acid solution.

Pour about 50 cc of barium hydroxide into a 250 cc beaker. Add 2 or 3 drops of phenol phthalein and notice the red color of the indicator. Place the terminals of the conductivity apparatus in the barium hydroxide solution and notice that the lamp lights up.

Slowly pour *very* dilute sulfuric acid into the beaker and stir with a glass rod. Notice the formation of white precipitate and, at the same time, the red color becomes fainter and the light dimmer. Continue to add sulfuric acid very carefully until the red color disappears altogether. Has the light also been extinguished? Now add 4 or 5 cc of sulfuric acid. Does the light bulb again glow? Explain.

Chapter 56

CHEMICAL INDUSTRIES

Many chemical processes have developed into vast industries which determine the economic life of a nation. Chemical industries are really a combination of "farm" and factory. The "farm" supplies the raw materials and the factory converts these raw materials into finished products. Some industrial countries—England and France for example—have highly organized factories but relatively poor "farms." As a result, these countries must import a large proportion of their raw materials. Other countries like Canada and the United States are in a more favorable position. Their "farms" supply an abundance of raw materials so that they are less dependent upon imports.

Chemical industries are of three main types. First there are those which depend entirely upon nature for their raw materials. Industries of this type are the paper and sugar industries. The chemist cannot make sugar or cellulose so he is entirely dependent upon nature.

In other industries the chemist imitates and often improves upon the products of nature. These industries include rubber and fabrics. Rubber is a natural product but the chemist can also make it. In fabrics, wool is an animal product and cotton a vegetable product. But the chemist can make rayon and nylon and many other fabrics from simple starting substances like coal and oil.

A third group has no counterpart in nature. Products in this group are entirely man-made. Plastics, explosives, and some of the new drugs belong in this category.

The soap industry cuts across the boundaries of this classification. The industrial chemist needs animal fats or vegetable oils as starting materials. These he treats with sodium or potassium hydroxide to make soap.

This is a varied list of industries—too extensive to consider in this book. We will, however, make a selection from the three groups beginning with the manufacture of sugar and paper.

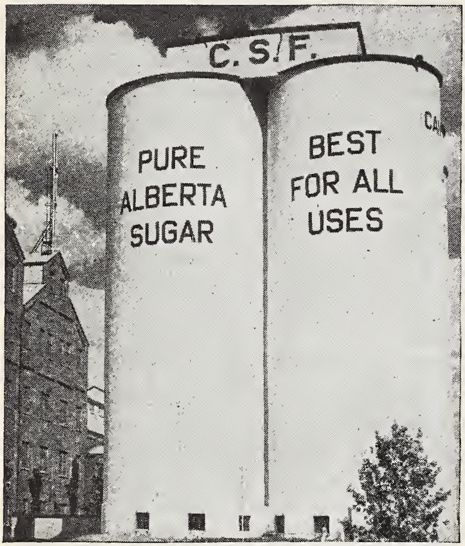
SUGAR

Cane sugar is usually called sucrose by the chemist. It is a carbohydrate and its chemical formula is $C_{12}H_{22}O_{11}$. The natural sources of sucrose are the sugar cane and the sugar beet. The sugar cane requires a subtropical climate and a high rainfall. It thrives in such places as Puerto Rico, Cuba and the Philippines.

The sugar beet thrives in a temperate climate. It needs rain during the spring and summer, but a dry autumn since the beets rot in wet ground. Sugar beets contain about 18 percent of sucrose. They are hard and tough and are not good eating.

In spite of popular opinion to the contrary, the refined sugar from the sugar beet is identical with that from the sugar cane. Indeed, it is also identical with the refined sugar from the maple. The sugar from the maple, however, is rarely refined. If it were, it would lose its characteristic flavor and, in consequence, would lose its commercial value.

Manufacture of Sugar. The beets are washed sliced, and shredded. The slices are then stirred in hot water which dissolves the sucrose. The solution is then filtered to remove all solid particles. The next step is the addition of lime, $Ca(OH)_2$, to precipitate certain organic compounds which are in the solution. The solution is then filtered again, and, at this stage, it is usually bleached with sulfur dioxide to remove the yellowish color. The solution is now ready to be concentrated by evaporation.



Courtesy Alberta Government

Fig. 56–1. Beet sugar plant of Canadian Sugar Industries at Picture Butte, Alberta.

Concentration in Vacuum Pans. If the solution were heated in an open vessel the sugar would scorch and char. To prevent this the solution is poured into a cooking device called a "vacuum pan." The pan is sealed and some of the air is pumped out of it. This reduces the pressure in the pan and, as a result, the boiling point of the solution is reduced. Actually, the sugar solution or syrup boils at about 70° C., a temperature at which sugar does not char.

The solution is heated by steam, evaporation takes place, and eventually crystals begin to separate. The syrup is then ready for the next operation in a centrifuge.

The Centrifuge. A centrifuge is a wire basket into which the slurry of crystals and liquor is placed. It is whirled rapidly by a motor and the liquor, called molasses, is forced out and caught in an outer container. The sugar crystals, which are retained in the basket, are washed free of molasses by a spray of water. The crystals are then transferred to a screen and dried by a current of hot air.

Molasses is a mixture of sugars called dextrose and fructose. It will not crystallize like sucrose. Molasses is used as a sweetening syrup. Some is fermented to form alcohol, and some is mixed with the beet pulp and used as cattle feed.

PAPER

Wood contains about 50 percent of cellulose ($C_6H_{10}O_5$) which is used in paper making. The manufacture of paper from wood is essentially a process of separating the cellulose fibers from other substances such as lignin and resins, present in the wood, and pressing these fibers together into paper. Paper can be made in at least four ways, but we will consider only the so-called *mechanical* and *chemical processes*. In either of these processes, the wood is aged for two or three years after the trees are cut down. The bark is then stripped off and the wood is ground to fine shreds. This is mixed with water to form wood pulp.

The Mechanical Process. This process simply uses the shredded wood. The pulp is poured on to the screen of a paper machine where it is dried and forms a web of paper. This is the cheapest form of paper and has little strength. It is used for newspapers. This paper contains objectionable lignin and resins and it slowly turns yellowish-brown when exposed to air.

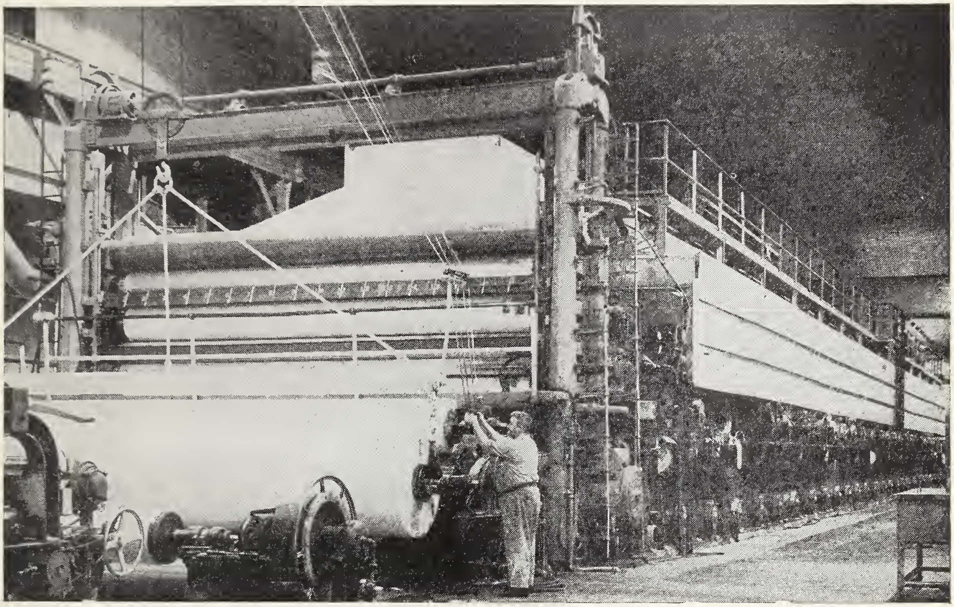

Trotter Studio

Fig. 56–2. The dry end of a paper machine. This machine, located in the Thunder Bay mill of the Abitibi Power and Paper Company, Ltd., is 228 inches wide and is capable of running 1400 feet of paper a minute or roughly seven tons an hour.

The Chemical Process. The chemical process, as the name implies, is a method of treating the pulp with various chemicals to improve the strength, appearance and printing qualities of the paper. First of all, the lignin and resins must be removed. These substances vary with the type of tree. As a result, the chemicals used are not the same for evergreen trees (such as the pine, spruce and hemlock) as for deciduous trees (such as the birch and poplar).

The pulp from deciduous trees is cooked with caustic soda since this compound will best remove the gums and resins in this type of wood. This is called the *soda process.* The pulp from evergreen trees is treated with calcium bisulfite, $Ca(HSO_3)_2$, and this is called the *sulfite process.*

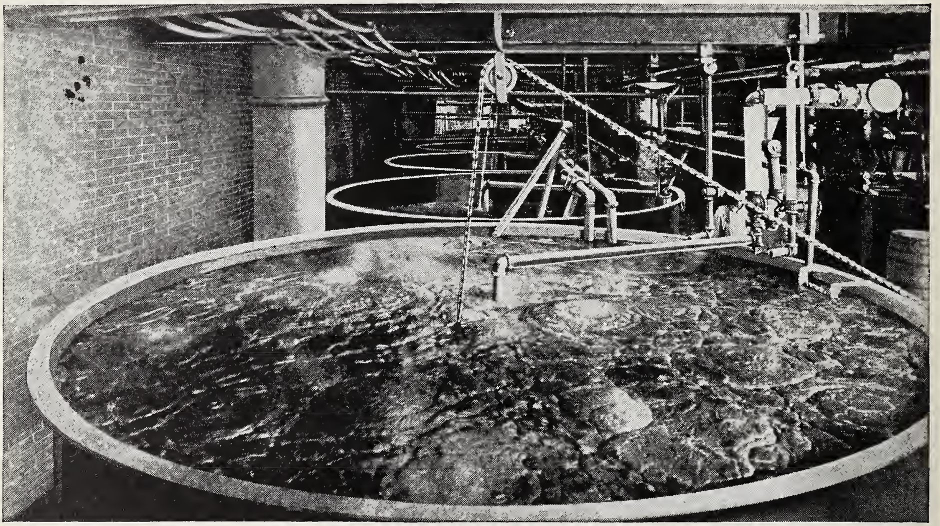
The Sulfite Process. The shreds are cooked with high pressure steam and calcium bisulfite for several hours. The lignin and resins dissolve in the bisulfite and are removed by repeated washing of the pulp.

Almost 50 percent of the original wood is lost by either of these processes. But the remaining "chemical wood pulp" is almost pure cellulose. Residual impurities impart a yellowish color to the pulp so that it is necessary to bleach it with chlorine.

Beating the Pulp. The pulp is now transferred to a tub where it is beaten by a cylindrical drum. The purpose of the beating is to roughen and fray the fibers so that they will adhere to each other and make a strong paper. Fillers and sizing are also added and are thoroughly mixed with the pulp. Resin is usually used for sizing. This is necessary to fill up the pores. Otherwise the paper would be like blotting paper and would not take ink. China clay or calcium sulfate are used as fillers or loading materials to make the paper opaque and to give it a smooth surface.

The Papermaking Machine. The milky fluid from the vat is then ready for the final operations in the papermaking apparatus. This is a series of machines, about 100 yards long. It is entirely automatic, and is one of the most efficient devices in chemical industry.

First the fluid is poured on to a moving wire screen which moves forward and is shaken sideways at the same time. The motion of the screen shakes out much of the water and the cellulose fibers cohere to form a mat or web. The web then passes through a suction box where more water is removed. It is then passed through rollers where still more water is squeezed out. Finally the mat passes over steam heated rollers. The resin now melts and seeps into the paper, filling the pores. As the paper emerges from the dry end of the machine it is wound into rolls.



Courtesy Swift & Company

Fig. 56–3. Huge soap kettles with a capacity of several thousand pounds.

SOAP

Soap is formed when fats or oils are decomposed by sodium hydroxide or potassium hydroxide. Sodium hydroxide forms a hard soap; potassium hydroxide a soft soap as in liquid soaps and shaving creams. Animal fats such as beef fat, lard, or tallow are suitable. Vegetable oils such as cottonseed oil, coconut oil, olive oil and many others may also be used.

A soap must have certain properties. It must be soluble in water, it must form suds, and it must not be too hard. To give these properties a mixture of fats and oils is used. Beef and mutton fat, for instance, would form a soap that was too hard, whereas coconut oil would form a soap that was too soft.

Soap is a Salt. To make sodium hydroxide and fat react chemically it is necessary to boil them for some hours. The reaction is

fat + sodium hydroxide → soap + glycerine.

Soap is the sodium salt of a fatty acid. The chemical name of one of these salts is sodium stearate. Glycerine is an important by-product in the soap industry.

The Manufacture of Soap. Ordinary toilet and laundry soaps are made in an enormous steel kettle. The kettle may be 30 feet in diameter and 35 feet deep. More than 100,000 pounds of soap may be made in a single kettle.

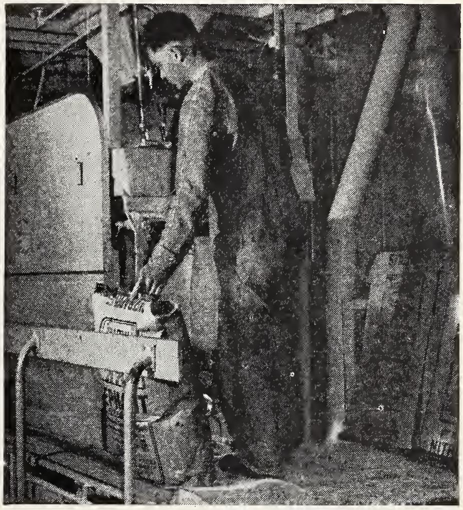
The mixture of fats and oils is pumped into the kettle and a solution of sodium hydroxide is added. The base is added in sufficient quantity to react with the fatty acids released from the fats and oils. The contents of the kettle are then heated by steam which enters the bottom of the kettle through a perforated coil. This steam also stirs up the mixture and so helps the substances to react. Usually the heating process takes about four hours.

When the soap is made salt is shovelled into the kettle, which causes the soap to separate from solution. The soap is lighter than the water and so rises to the top. It is pumped out of the kettle and washed to remove any remaining sodium hydroxide. This compound, if left in the soap, would be harmful to skin and hair.

The soap is then chilled on steel rollers, dried by hot air and cut to shreds. The shreds are sprayed with perfume, pressed and mixed, and then squeezed through a die to form a long bar. The bar is cut into cakes in a stamping machine, and the cakes are either wrapped in paper or boxed.

FERTILIZERS AND EXPLOSIVES

When plants grow they take nutrients out of the soil. As a result, the soil becomes impoverished and nutrients must be replenished. This is done by fertilizers which are essentially compounds of nitrogen, phosphorus, and potassium. We will discuss only the nitrogen fertilizers, the most important fertilizers.



Courtesy Consolidated Mining and Smelting Co., Ltd., of Canada

Fig. 56–4. Bagging ammonium nitrate fertilizer at the Cominco plant, Trail, B. C. The finished product looks like tapioca.

How are nitrogen compounds returned to the soil? For centuries farmers have recognized the value of manures, fish scraps, and even dried blood to replace the lost nitrogen. But these sources were far from fulfilling their needs. In the 19th century Chile saltpeter was imported for this purpose. Chile saltpeter is largely sodium nitrate ($NaNO_3$) and is an excellent fertilizer. It is a fabulous deposit, isolated on a desert plateau in northern Chile. No one, not even among geologists, is quite certain how it got there.

It was not until the early part of the present century that chemists learned how to make the nitrogen of the air combine with other elements. This process is called *fixation* of nitrogen. It is one of the most important of all chemical reactions since it makes available the inexhaustible supply of nitrogen in the atmosphere.

Fixation of Nitrogen. Nitrogen is an inactive gas and the chemical problem was to make it combine with other elements on a large scale. A German chemist named Haber succeeded in doing this in the following way.

He compressed a mixture of nitrogen and hydrogen under an exceedingly high pressure of 200 atmospheres. The mixed gases were then heated to about 450° C. and passed over a catalyst. Under these conditions the gases combined to form ammonia, a pungent gas.

Or,

$$N_2 + 3H_2 \rightarrow 2NH_3$$

This is an exceedingly important reaction. Ammonia is the parent of a large number of nitrogen compounds and the Haber Process is a basic chemical procedure in every industrialized country. For instance, if ammonia is treated with dilute sulfuric acid the following reaction takes place,

$$2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$$

Ammonium sulfate is a salt, a white solid. It is widely used as a fertilizer. Notice again that the nitrogen of ammonium sulfate comes from the air—it is fixed nitrogen. When mixed in the soil, it is absorbed by the roots of plants. The plants decompose it and from the decomposition products they form the proteins they need to build up their own cell structure.

NITRIC ACID

Another important nitrogen compound is nitric acid. This compound is needed for making explosives, dyes, drugs and many other substances. Nitric acid is made by oxidizing ammonia with the oxygen of the air. To do this, ammonia and air are passed through a hot platinum gauze which acts as a catalyst. The reaction is

$$NH_3 + 2O_2 \rightarrow HNO_3 + H_2O$$

The nitric acid, which is a vapor at the high temperature of the reaction, condenses and dissolves in the water that is also formed.

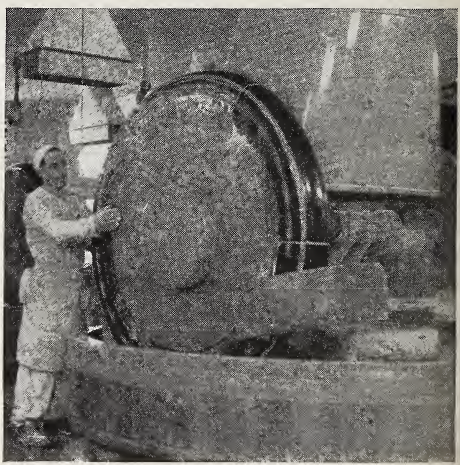
EXPLOSIVES

Explosives, which have already been discussed at some length in Chapter 24, are made from nitric acid. Both dynamite and T.N.T. have been discussed in this chapter.

Dynamite is made from glycerine, $C_3H_5(OH)_3$, a by-product of the soap industry. The reaction is

$$C_3H_5(OH)_3 + 3HNO_3 \rightarrow C_3H_5(NO_3)_3 + 3H_2O$$

The compound $C_3H_5(NO_3)_3$ is nitroglycerine, an oily, unstable liquid which explodes on the slightest shock. To make it safe to handle, nitroglycerine is absorbed by sawdust or charcoal. The product is called dynamite.



Courtesy Canadian Industries Limited

Fig. 56-5. At the "Mixing House" in the explosives plant in Beloeil, Que., nitroglycerine is mixed with the non-explosive ingredient to make dynamite.

When dynamite is exploded, the following reaction takes place,

$$4C_3H_5(NO_3)_3 \rightarrow 12CO_2\uparrow + 10H_2O\uparrow + 6N_2\uparrow + O_2\uparrow + \text{heat}$$

Notice that all the products are gases. The heat evolved in the reaction causes the gases to expand, thereby creating an explosive force. Notice also that dynamite is a smokeless powder because, unlike gunpowder, there are no solids among the products.

Courtesy Canadian Industries Limited

Fig. 56–6. Rock, mud, and water rise 1,000 feet into the air as 36,000 pounds of dynamite are used to unplug a diversion tunnel on the Manicougan River, Quebec.

Trinitro toluene (T.N.T.). T.N.T. is formed by the nitrogen of toluene, $C_6H_5CH_3$, obtained from coal tar and petroleum. The reaction is

$$CH_3C_6H_5 + 3HNO_3 \rightarrow CH_3C_6H_2(NO_2)_3 + 3H_2O$$

T.N.T. is a solid which melts at 80° C. This low melting point is a great advantage since the compound can easily be melted and poured into shells. It is quite safe to handle because it is not affected by ordinary shocks. When detonated, however, it explodes violently, giving gaseous products in a manner similar to dynamite.

SYNTHETICS

The chemist has not yet synthesized the most complex substances found in nature, substances such as cellulose, wool and silk. But he has made a wide variety of synthetic materials. The so-called "synthetics" are organic compounds, and are usually made from such abundant raw materials as air, water, coal, petroleum, and natural gas. Rubber and plastics are probably the most important synthetics.

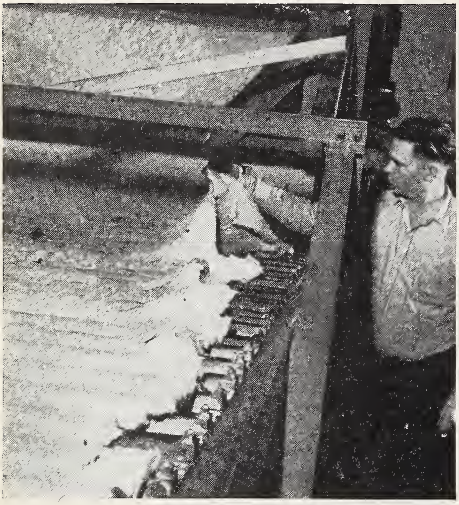
RUBBER

Natural rubber is obtained from a tropical plant cultivated chiefly in Malaya, Indo-China, and the East Indies. When the bark of a rubber plant is cut, a milky fluid called latex oozes out. Latex is an emulsion of rubber globules in water. When a dilute acid is added to latex, the rubber coagulates. It is then pressed between rollers to thin sheets of rubber.

Chemists have now synthesized rubber from the products of coal and petroleum. As a result, industrialized countries are no longer dependent upon the imports of latex from tropical countries. Actually four different types of rubber are manufactured but only one, Buna S, will be discussed here.

Buna S is the cheapest of the synthetic rubbers and it most nearly resembles natural rubber. Buna S is manufactured by agitating a mixture of butadiene and styrene in soapy water for several hours. Both butadiene and styrene are complex hydrocarbons obtained from petroleum, natural gas, or coal. They combine to form a milky emulsion of rubber particles which resembles latex. As in the case of latex, acid is added to coagulate the rubber and the product is filtered and dried.

The rubber is heated with sulfur, a process called *vulcanization,* to make it tough, elastic and resistant to wear. As explained on page 256, the durability of rubber is further increased by the additions of carbon black.



Courtesy Polymer Corporation, Limited

Fig. 56–7. Synthetic rubber crumb as it passes from the drier to the extruder.

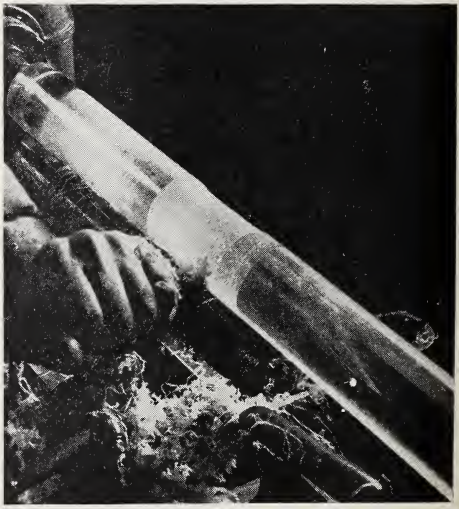
PLASTICS

The most versatile of all synthetics are plastics. The word plastic means a substance that can be softened by heat and then molded into any desired shape. Some plastics are *thermoplastic;* that is, they can be repeatedly softened by heating and hardened again by cooling. Other plastics are *thermosetting* which means that the material is changed by heat into a permanently infusible solid. Lucite or Plexiglas is a thermoplastic, and Bakelite is a thermosetting plastic.

Bakelite is made by heating a mixture of phenol (a coal tar product) and formaldehyde in an alkaline solution. They form an amber-colored plastic which will adsorb dyes. If the plastic is heated it can be melted and poured into a mold of any desired shape. On cooling to a solid, it forms Bakelite which is an infusible solid. Many familiar articles are made of Bakelite—door knobs, radio cabinets, bottle caps, electrical insulators, and a host of other things.

Lucite or Plexiglas. Lucite is a complex organic substance made from petroleum or natural gas, coal, salt and water. This is the most transparent substance known, even more transparent than glass. A Lucite rod will conduct light from one end to the other. This property is useful to dentists and surgeons since they can direct a light, by means of a Lucite rod, to any part of a patient without risk of burning him.

Lucite and Plexiglas can be machined, sawed, and drilled, just like wood. This property greatly extends the uses that can be made of it. The Lucite lenses are the "unbreakable glass" in spectacles. It is also used for windows in airplanes and for safety glass in automobiles.

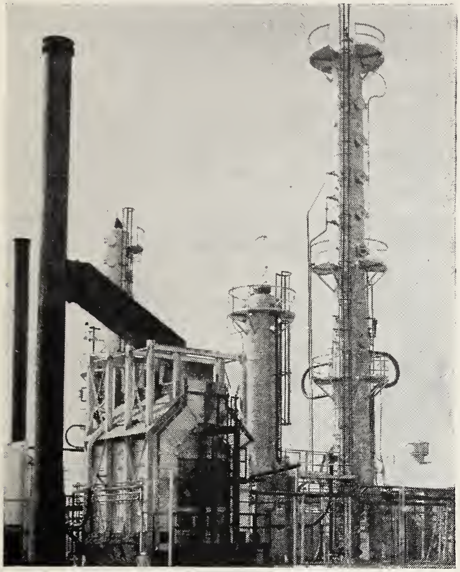


Courtesy du Pont Company

Fig. 56–8. Machining Lucite on a lathe.

PRODUCTS FROM PETROLEUM AND NATURAL GAS

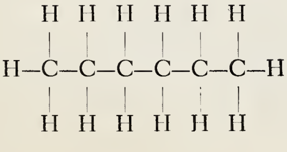
As stated above, plastics and rubber are made from petroleum and natural gas. These two natural products are the starting point of many valuable products.



Courtesy Universal Oil Products Company

Fig. 56–9. A petroleum cracking unit.

Let us turn back for a moment to the refining and the cracking of petroleum on pages 238 and 239. Gasoline, it states, is a mixture of pentane (C_5H_{12}), hexane, (C_6H_{14}), heptane, (C_7H_{16}), and octane (C_8H_{18}). Notice that these compounds are hydrocarbons which can be represented by the general formula C_nH_{2n+2}, where *n* represents the number of carbon atoms per molecule. Hexane can also be written structurally as



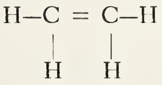
$$\begin{array}{cccccccc} & \mathrm{H} & \mathrm{H} & \mathrm{H} & \mathrm{H} & \mathrm{H} & \mathrm{H} & \\ & | & | & | & | & | & | & \\ \mathrm{H}- & \mathrm{C}- & \mathrm{C}- & \mathrm{C}- & \mathrm{C}- & \mathrm{C}- & \mathrm{C} & -\mathrm{H} \\ & | & | & | & | & | & | & \\ & \mathrm{H} & \mathrm{H} & \mathrm{H} & \mathrm{H} & \mathrm{H} & \mathrm{H} & \end{array}$$

This formula shows that the carbon atoms in the molecule are linked together to form a chain. As we would expect by reference to the valence table, the carbon atoms have four bonds and the hydrogen atoms one bond.

In the cracking process, long chain molecules of kerosene or fuel oil are broken by the heat and pressure. Consider, for example, the various ways in which the molecule $C_{13}H_{28}$ may be broken

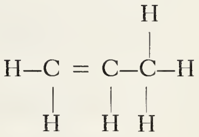
$$\begin{array}{lll} C_{13}H_{28} & \rightarrow & C_8H_{18} + C_5H_{10} \\ & \text{or} & \\ & \rightarrow & C_7H_{16} + C_6H_{12} \\ & \text{or} & \\ & \rightarrow & C_6H_{14} + C_7H_{14} \\ & \text{or} & \\ & \rightarrow & C_{10}H_{22} + C_3H_6 \\ & \text{or} & \\ & \rightarrow & C_{11}H_{24} + C_2H_4 \end{array}$$

The molecules on the left are of the gasoline type (C_nH_{2n+2}). But the molecules on the right are hydrocarbons of a different type (C_nH_{2n}). Consider the compound C_2H_4. Its name is ethylene. What is its structure? The only way it can be written is



$$\begin{array}{ccccc} \mathrm{H}- & \mathrm{C} & = & \mathrm{C} & -\mathrm{H} \\ & | & & | & \\ & \mathrm{H} & & \mathrm{H} & \end{array}$$

A similar type of compound is (C_3H_6), or



$$\begin{array}{cccccc} & & & & \mathrm{H} & \\ & & & & | & \\ \mathrm{H}- & \mathrm{C} & = & \mathrm{C}- & \mathrm{C} & -\mathrm{H} \\ & | & & | & | & \\ & \mathrm{H} & & \mathrm{H} & \mathrm{H} & \end{array}$$

Compounds of this type (C_nH_{2n}) all have a double bond which makes them very reactive. Indeed, compounds with a double bond are the important ones in synthetic chemistry.

Natural gas is largely a mixture of methane (CH_4) and ethane (C_2H_6). Ethylene can also be made by the decomposition of natural gas. It is one of the most important compounds in industry. Ethylene combines with bromine to form ethylene dibromide ($C_2H_4Br_2$), an important constitutent of "ethyl" gasoline. It reacts with water to form ethylene glycol used as an antifreeze. It also reacts with chlorine and hydrochloric acid and from the products obtained in this way an almost unbelievable number of useful compounds can be made.

And so it is with other petroleum products. Such derivatives as paints, plastics, rubber, explosives, fertilizers, perfumes, detergents, glycerine and even alcohol are made on a large scale from petroleum.

Products from Natural Gas. What is true of petroleum is also true of natural gas. As petroleum becomes harder to find, many of the chemical industries now based on petroleum will use natural gas as their raw material. Already natural gas can be converted into gasoline or Diesel fuel by a process somewhat similar to that described on page 240. This history of natural gas is really a Cinderella story. It began as an unwanted and discarded stepchild and now it promises to be one of the most basic commodities in industry.

THINGS TO REMEMBER

Natural sources of sugar, a *carbohydrate,* are sugar cane and sugar beet.

To extract *sugar,* beets are sliced and stirred with hot water. The solution is concentrated in vacuum pans until crystals form. The crystals are then whirled in a centrifuge to separate them from molasses.

Paper is made from wood. Wood is first shredded to a pulp. Lignin is then removed from the pulp by chemicals, and the fibers of the purified pulp are freed from water on a moving wire screen.

Soap is the sodium salt of a fatty acid.

Fertilizers enrich the soil. They are essentially compounds of nitrogen, phosphorus, and potassium.

The *fixation of nitrogen* is the combination of nitrogen of the air with other elements.

Synthetics are organic compounds made from raw materials such as air, water, coal, petroleum, and natural gas.

A *thermoplastic* can be softened by heat; a *thermosetting plastic* cannot be softened by heat.

QUESTIONS

A

1. What is a carbohydrate? Give an example.
2. What is molasses? What is it used for?
3. What is cellulose? Give an example.
4. What is chemical wood pulp?
5. Explain the purpose of fillers and sizing in papermaking.
6. Name the important by-product in the soap industry.
7. Write the word equation for the reaction in a soap kettle.
8. (*a*) Explain why it is necessary to enrich soil with nitrogen fertilizers.
(*b*) Name three common nitrogen fertilizers.
9. What is meant by the vulcanization of rubber.
10. Name a source of (*a*) natural rubber; (*b*) synthetic rubber.
11. Write the structural formula for pentane.

B

12. Discuss briefly the essential steps in the manufacture of sugar.
13. What are vacuum pans? How do they operate? What is their purpose?
14. Briefly describe the sulfite process in paper making.
15. Explain briefly how soap is made.
16. (*a*) What is meant by fixation of nitrogen?
(*b*) Describe a method by which nitrogen is fixed.
17. (*a*) What is dynamite?
(*b*) Why is dynamite an explosive substance?
18. (*a*) What is Buna S?
(*b*) How is it made?
19. Describe some of the important properties of Lucite.
20. Explain the two different kinds of compounds formed in the cracking process.

Chapter 57

CHEMISTRY AND THE CONSUMER

Let us now take stock of our chemical knowledge. We might well ask, What is the use of it? An idealist might reply that knowledge is its own reward and that without knowledge there can be no wisdom. Some might answer that chemistry tells us a good deal of the world about us and makes it a more interesting place to live in. Others might concede that chemistry helps us to live more intelligently.

This last point is worth examining a little more closely. Until relatively recent times there has been much superstition associated with scientific phenomena. Even today it is still fairly common in the treatment of disease. A knowledge of science dispels a fear of the unknown and averts superstition. At least the knowledge will serve this purpose if it is usefully applied. One has only to consider the extravagant claims in advertising, both over the radio and in the newspapers, to be convinced that false claims of unscrupulous vendors were not limited to the Dark Ages.

Man is, of course, vitally concerned with his health. This is a field where sound chemical knowledge can ward off the dangers of quackery.

Health is closely related to food. And food is the item that looms largest in the family budget in times of rising prices. Are the most expensive foods the most nutritious? What is a balanced diet? Do foods change chemically when they are digested? Are food preservatives harmful? Let us examine some of these questions.

The Purpose of Food. The body is like an internal combustion engine that gets its energy from food. Food is "burned" in the body and the energy released in the combustion reactions serves several purposes. First it keeps the body warm, at a temperature of 98.6° F. The energy also allows us to operate our muscles; in other words, to do work. Even speaking and breathing require energy —and energy is also needed to maintain a beating heart.

Food is also needed to form tissue. No child could grow without food to supply this living material. Even when we are fully grown food is still needed for this same purpose. Throughout life the cells of the body wear away and disintegrate so that an essential function of food is to make good these losses in living tissue.

Essential Foods in an Ordinary Diet. To supply the various needs of the body a "balanced" diet is necessary. This should include carbohydrates, fats, proteins, minerals and vitamins. When these substances enter the stomach and intestines they are attacked by "juices" and enzymes and are decomposed to smaller molecules, a process called digestion. The digested food particles are small enough to pass through the wall of the intestines and into the blood stream. They are carried to the cells where the repair and energy reactions take place.

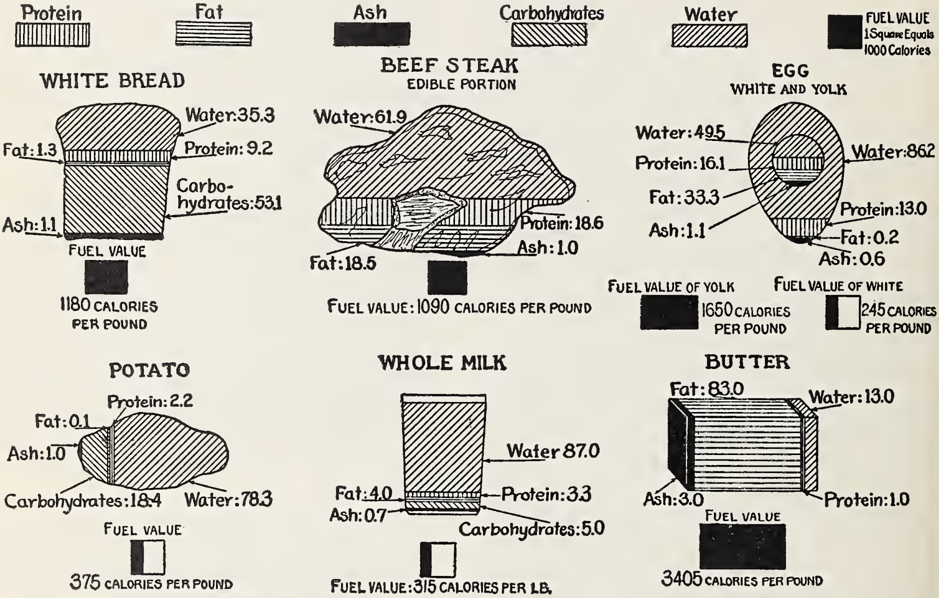


Fig. 57–1. The composition and heat value of some common foods.

Carbohydrates. Carbohydrates, which are chiefly sugar ($C_{12}H_{22}O_{11}$) and starch ($C_6H_{10}O_5$), are made only by plants. They are the most abundant source of energy. Cereals, rice, and potatoes all contain a good deal of starch; bread, "the staff of life," contains more than 50 percent of it.

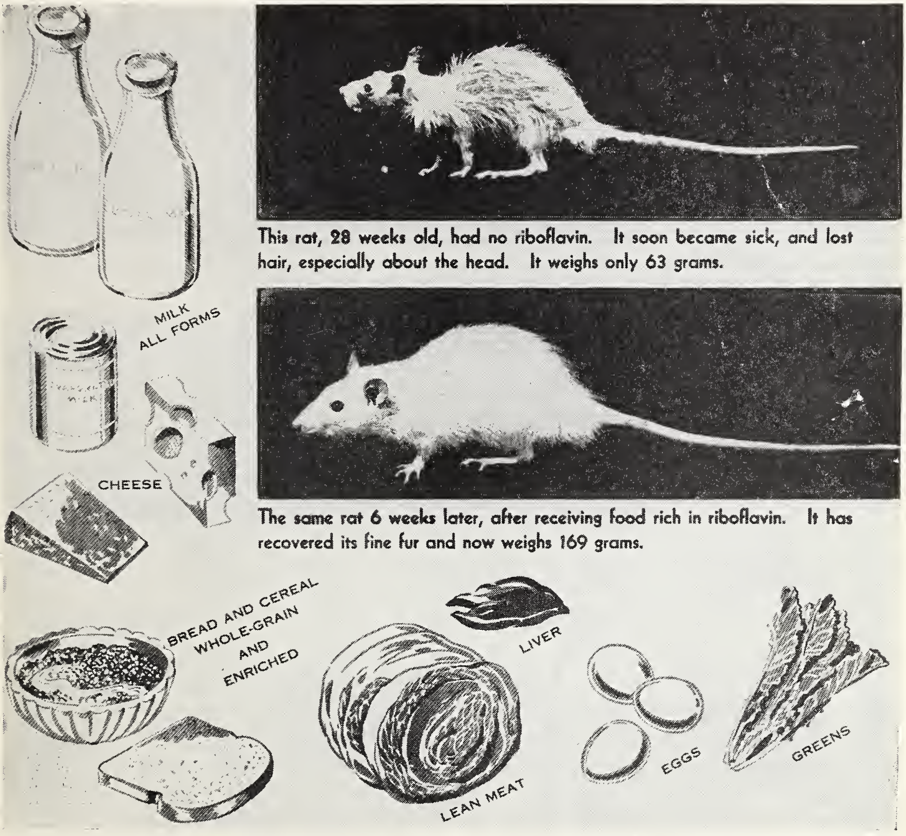
Proteins. Proteins contain nitrogen as well as carbon, hydrogen and oxygen. They are essential constituents in the cells of plants and animals. For this reason much of our food consists of the tissues of other organisms. Beef, mutton, pork, and fish are good sources of protein. These articles of food are considerably more expensive than the carbohydrates. Proteins, however, occur in some vegetables such as peas, beans, peanuts, and soybeans. Eggs are also rich in protein.

Fats. Fats are compounds of carbon, hydrogen and oxygen, but they have a higher percentage of carbon than carbohydrates. For this reason they can be regarded as concentrated fuels. Fats occur in animals and plants. Bacon and fat meats, butter and cream are good animal sources of it. Many vegetable products, such as margarine, olive oil, and cottonseed oil, also contain it.

Minerals. Minerals are needed to build up tissue and for various body functions. Small quantities of calcium, phosphorus, potassium, magnesium, iron, sulfur and sodium are essential. Calcium and phosphorus, for example, are necessary for making bones and teeth; iron is a vital ingredient of the blood. Minerals are present in all green vegetables which should therefore be included in the daily diet.

Foods such as rice, wheat, potatoes, and apples have their minerals concentrated in their outer layers. As a result, the minerals are lost in the peelings of apples and potatoes. The same is true of polished rice and white flour since the outer layers of rice and wheat grains have been removed in the processing.

Vitamins. If a person were given a diet of only carbohydrates, fats, proteins, and the essential minerals, illness would soon overtake him. This is because his diet would lack certain "vital" substances called vitamins. Diseases caused by lack of vitamins have been known for centuries, but the vitamins which prevent these diseases have been isolated and identified only within the past fifty years. In the days of sailing ships sailors, during long voyages at sea, were often stricken with scurvy,



This rat, 28 weeks old, had no riboflavin. It soon became sick, and lost hair, especially about the head. It weighs only 63 grams.

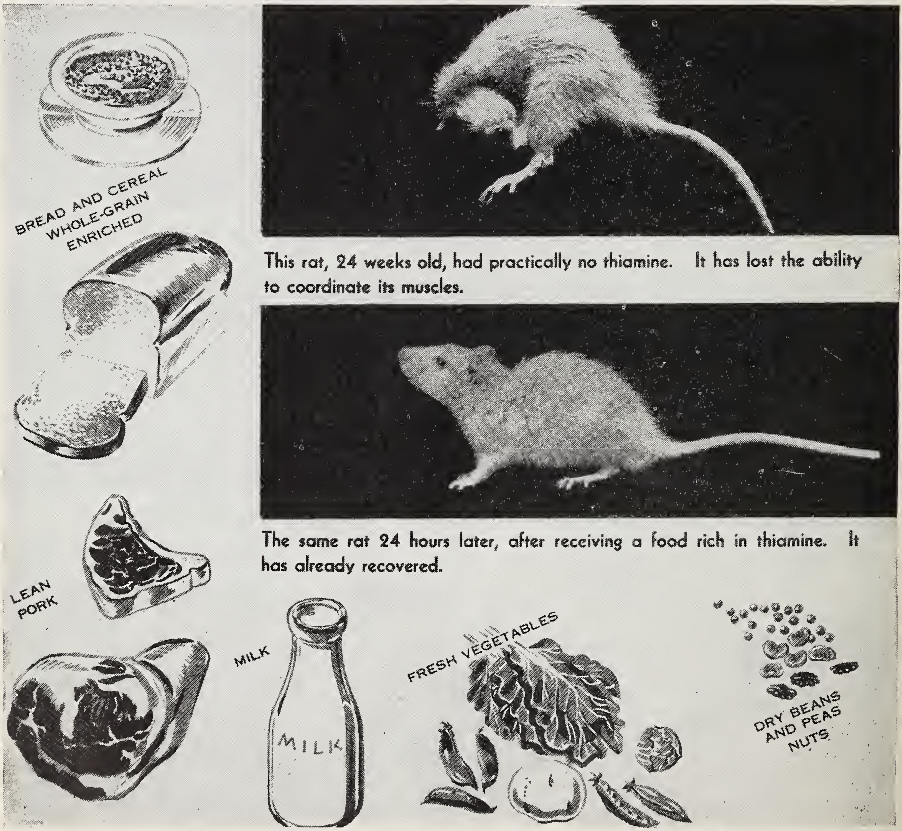
The same rat 6 weeks later, after receiving food rich in riboflavin. It has recovered its fine fur and now weighs 169 grams.

Courtesy U. S. Department of Agriculture

Fig. 57–2. Riboflavin promotes health by helping body cells use oxygen.

a disease that caused loosening of the teeth, bleeding of the gums, and soreness of the joints. Even as early as 1720 it was known that lime juice and citrus juices would cure this disease. But it was not until the present century that scurvy was known to be caused by lack of Vitamin C, a vitamin present in citrus fruits.

Vitamins occur in minute quantities in many natural foods. They are an essential part of a balanced diet. Vitamins can be regarded as body regulators. Without them various chemical changes will not take place in the body and deficiency diseases will result. When first isolated, their chemical composition was unknown, and so they were named after the first six letters of the alphabet. More recent research has proved that most of the vitamins are not just single compounds. Vitamin B, for example, is a complex of at least three substances, thiamin, riboflavin, and niacin.



This rat, 24 weeks old, had practically no thiamine. It has lost the ability to coordinate its muscles.

The same rat 24 hours later, after receiving a food rich in thiamine. It has already recovered.

Courtesy U. S. Department of Agriculture

Fig. 57–3. Thiamin (vitamin B_1) is needed by body cells to use carbohydrates.

Vitamin A. A deficiency of this vitamin causes impaired vision, night-blindness, and skin eruptions. Good sources of Vitamin A are yolk of egg, fish-liver oils, butter and vegetables, particularly carrots.

Vitamin B Complex. This substance, originally thought to be one compound, contains the B vitamins, thiamin, riboflavin, and niacin. A deficiency of it results in *beriberi* (which causes weakness, stunted growth, and neuritis), *dermatitis,* (characterized by lesions of the skin), and inflammation of the skin and eyes. Niacin and riboflavin are present in milk, eggs, and fresh vegetables. Thiamin is found most abundantly in whole grain foods and yeast. The removal of the husks of grain, as in the manufacture of white flour and polished rice, results in loss of this valuable vitamin.

Vitamin C. As already stated, a lack of this vitamin causes scurvy. It occurs in citrus and other fruits, also in tomatoes and other vegetables. However, the vitamin is decomposed by the oxygen of air and also by cooking. For this reason, only fresh, raw fruits are a good source of it.

Vitamin D. A deficiency of vitamin D prevents the proper absorption of calcium and phosphorus in the bones, and is the cause of rickets in children. Milk, eggs, butter and various liver oils are natural sources of this vitamin.

Synthetic Vitamins. All the vitamins except D have now been synthesized by the chemist. And vitamin D can be produced in some foods by ultraviolet light.

Vitamins, particularly B and C, are now manufactured on a large scale. This means that refined foods like white flour and polished rice can be enriched. It also means that a typical diet of meat, potatoes, white bread, coffee and sugar which is deficient in vitamins can be enriched by taking vitamin pills. But it also means that the radio announcer has an opportunity to sell his wares whether they are needed or not. It is well to bear in mind that sufficient vitamins are present in a *varied* diet of natural foods and that, unless prescribed by a physician, vitamin pills may serve no useful purpose.

Milk, A Well-Balanced Food. Milk contains all the essentials of a complete diet for growing infants—protein, fat, sugar, calcium salts and other minerals, and some vitamins. It can be fermentated in various ways into more concentrated foods. Cheese, for example, which is made in this way, contains all the proteins and fat of the original milk.

Cooking of Foods. The common practice of cooking foods is based on common sense. The flavor of foods is improved by cooking, but this is by no means the most important reason. Cooking destroys germs thereby making the foods more edible as well as preventing their decay. Pork, for instance, may contain tiny worms called trichina, which can induce serious illness unless they are destroyed by cooking. Similarly, uncooked beef may contain a tapeworm which could likewise be transferred to the consumer.

Still another advantage of cooking is that foods are made more digestible. Starch granules have a tough cell wall made of cellulose which cannot be digested in the human stomach. When potatoes are boiled or baked the cell walls are broken so that the starch is then released and is available as a food.

Foods are destroyed by Bacteria. The atmosphere contains myriads of microscopic organisms called yeasts and bacteria. Yeasts and bacteria are minute plants. A yeast tablet contains millions of tiny yeast plant cells. Neither yeast nor bacteria contain green chlorophyll, and, as a result, they are unable to manufacture food out of the carbon dioxide and water vapor of the air. Instead, they attack dead organic material and decompose it. In this way, new food materials are made available for growing plants. Indeed, unless bacteria decomposed organic material, the available food supplies of plants would dwindle and eventually become exhausted. Although the action of yeasts and bacteria is an essential provision in nature, the decomposition of foods which they cause can have dangerous effects. Vegetables, fruit, meat, eggs, and milk are all attacked by them. The flavor of foods is changed as new compounds are formed, and in some cases the foods develop bad odors and may even become poisonous. How can foods be protected against the action of bacteria? This may be done by canning, by refrigeration, and by the use of preservatives.

Fig. 57–4. Louis Pasteur (1822-1895). Chemist and bacteriologist. He discovered the nature of fermentation. He also found the cause of some contagious diseases and discovered a means of preventing contagion.

Canning of Foods. Canning is an effective method of conserving fruits and vegetables. When the fruits are plentiful they are cheap and they can be preserved for use in the winter and spring. In canning care must be taken to exclude all bacteria. Jars must be sterile and hands should be scrupulously clean. Even the fruit should be unbruised for otherwise bacteria may enter the broken covering of the skin.

The fruit is packed into jars which are then filled with syrup. The jars are placed in a boiler and almost covered with water. Rubber rings are fitted on to the jars and the glass covers put loosely in place. The water is then strongly heated and the heating process is continued long enough to destroy all bacteria. The cover is then sealed while the jar is still hot. The rubber seal makes the jar air tight, and so excludes all bacteria.

If the jars are stored in a cool dark place, the fruit is preserved indefinitely.

Pasteurization of Milk. The pasteurization of milk is a safety precaution rather than a method of destroying all bacteria. Raw milk, particularly if it is not certified, may contain tuberculosis and typhoid germs. If the milk is maintained at a temperature of about 145° F. for about 30 minutes all tuberculosis and typhoid germs are destroyed. This process is called *pasteurization.* The germs which turn milk sour are not destroyed by pasteurization but they are rendered inactive for some time. As a result, the milk is prevented from spoiling for a period of 48 hours or so.

Refrigeration. Bacteria do not develop at low temperatures so that meat, fruit and vegetables can be kept in good condition for days by placing them in cold storage. The most suitable temperature for storage depends on the nature of the food. Fish is best stored at 5° F., and meat and poultry at 10° F. At these temperatures they can be preserved for months. Fruits should be kept at a higher temperature, just above the freezing point of water. Fruits in cold storage are still alive and the purpose of the low temperature is to delay the ripening process. When fruits are removed from the refrigerator the ripening process again proceeds at a normal rate.

Preservatives. It has been known for centuries that certain preservatives will prevent food from decomposing. The use of salt and spices for this purpose are referred to in the Bible. The effect of preservatives is to destroy bacteria and to prevent them from entering the food. Another effective method of preserving meats such as ham or corn beef is to suspend them in the smoke of a wood fire. Smoke closes the pores and therefore excludes air. Before smoking, the meats should be treated with salt, and salt peter, and even sugar. All these substances are preservatives and they also help to retain the flavor.

A concentrated sugar solution also inhibits bacteria. We are familiar with the use of sugar as a preservative in jams and jellies. The paraffin wax poured on the top of home-made jam excludes the air. Still another harmless and effective preservative is vinegar.

In recent years harmful chemicals have been added to foods to preserve them. Fifty years ago farmers added formaldehyde to milk thereby making it possible to store milk for several days. Formaldehyde does not spoil the taste of milk but it seriously interferes with the digestive process. About the same time, laudanum, a derivative of morphine and a habit-forming drug, was given to babies as a "soothing syrup." Cases such as these were the cause of legislation—a Food and Drug Act—which supposedly protects the consumer against adulterated foods. Preservatives such as formaldehyde and boric acid are now forbidden by law. Others, which are still used, give an objectionable taste and flavor to foods and are dangerous to health. The use of sodium benzoate has caused much controversy. A certain small percentage is allowable, and if it is used at all it must be so stated on the label. Another chemical that may have harmful effects is sulfur dioxide used as a preservative of dried fruits.

Food Fads. Good nutrition is essential to good health and personal efficiency. Its importance cannot be stressed too much. It is not surprising that some people make extravagant and unfounded claims for the beneficent effects of certain foods and food processes. Indeed, most of us have some idiosyncrasy in the interest of "good nutrition."

An ever popular theme in magazine articles is the remarkable nutritional value of "natural foods." Such articles also condemn the refining process which undoubtedly removes certain nutrients from foods. Crystallized sugar and white flour for example, are refined foods. They are refined to make them white and improve their appearance. But is the nutritional loss really serious?

Some of the "experts" urge the use of honey, or raw sugar, or even molasses instead of refined cane sugar. It is true that honey and raw sugar have traces of minerals and vitamins not found in the refined sugar. And molasses is a good source of iron, without which anemia would develop. But we must remember that all the essential minerals and vitamins are provided in a mixed diet. Moreover, you do not have to get your iron from molasses—an even better source of it is green vegetables or yolk of egg.

It is also true that in the refining of white flour both minerals and thiamin have been lost. But if white flour is enriched, and it usually is, the lost minerals and vitamins are restored. There is no scientific evidence that refined white flour is less nutritious than whole wheat flour.

One could write at length on other food fads. But the point to bear in mind is that a race of supermen will not be developed by following the advice given in pseudo-scientific articles.

Aluminum Cooking Vessels. One other instance of groundless fear in the cooking of foods might be referred to. If vegetables are cooked in an aluminum saucepan, a dark stain or deposit is often formed. The dark deposit is not formed if a steel saucepan is used. Some housewives have concluded that aluminum reacts with vegetables to form a substance dangerous to health and, as a result, have discarded their aluminum ware.

Actually, the dark stain is iron and it has come from the vegetables. The reaction that has taken place is

$$2Al + 3Fe^{+2} \rightarrow 2Al^{+3} + 3Fe$$

In other words, some aluminum ions have replaced ferrous ions in the food. But aluminum ions are not harmful. Indeed, they are present in most vegetables. If an acid food like apples or tomatoes is cooked in the saucepan, the dark deposit on the saucepan disappears because the iron goes back into the food. There is no scientific evidence to support the idea that it is harmful to cook in aluminum dishes.

Self Diagnosis and Self Treatment. Another of the baneful effects of advertising over the radio is the widespread use of so-called patent medicines. These are drugs and medicines sold without a physician's prescription. The sale of patent medicines has become a vast business and for the customer it may be attended by dire risks. By using patent medicines the consumer is merely trying to treat symptoms—he is not remedying the causes. Such self treatment delays the correct diagnosis of his sickness and may result in irreparable harm.

One of the most popular and least harmful pain-relievers (or analgesics as they are called in medical parlance) is aspirin. Aspirin is used for headaches, colds, all kinds of pains, and even for rheumatism. A medical journal says of this relatively "safe" drug, "Aspirin may be and has been repeatedly shown to be potentially harmful, directly and indirectly, when taken indiscriminately. Its use may mask the symptoms of any number of serious diseases."

But aspirin is *relatively* harmless—most people have it in their medicine cabinets. Other patent medicines contain habit-forming drugs and still others claim to cure tuberculosis, epilepsy, and even cancer. This method of trial and error savors of the Dark Ages; it is not the scientific approach. It is hoped that a knowledge of chemistry will make one aware of the dangers of self-medication. The safe procedure is to get the diagnosis of a physician and then to follow his advice, which is intended to discover the cause of the affliction.

THINGS TO REMEMBER

Food supplies energy to keep the body at 98.6° F. and to enable us to do work. It also supplies materials to form living tissues.

A *balanced* diet should include carbohydrates, fats, proteins, minerals, and vitamins.

Carbohydrates are made only by plants. Common examples are sugar and starch.

Proteins are present in the cells of plants and animals. They are complex nitrogen compounds.

Fats occur in plants and animals. They are complex compounds of carbon, hydrogen, and oxygen.

Essential *minerals* in a diet are minute quantities of calcium, phosphorus, potassium, iron, magnesium, sodium, and sulfur.

Vitamins enable essential reactions in the body to take place. Without them deficiency diseases would result.

Cooking foods improves their flavor, makes them more digestible, and destroys bacteria.

QUESTIONS

A

1. State four essential uses of food.
2. How do food particles reach the cells of living tissue?
3. State the use of the minerals calcium and iron.
4. Why is whole wheat flour a better food than white flour?
5. (*a*) What are vitamins?
   (*b*) Why are they named after the first six letters of the alphabet?
6. Explain how a food can be made more digestible by cooking.
7. What is pasteurization of milk?
8. At what temperature can fish be preserved? Why is it preserved at this temperature?

B

9. What are carbohydrates, proteins, and fats? Give two examples of each, and state the particular purpose they serve as foods.
10. What is vitamin B? In what foods is it obtained? State the diseases that would result if vitamin B were omitted from the diet.
11. Write briefly on vitamins A, C, and D.
12. What are bacteria? Why should they be destroyed in foods?
13. Briefly explain the process of canning fruit. Give a reason for the various steps involved.
14. What are food preservatives? Give examples of both harmless and harmful preservatives.
15. Briefly discuss the merits of the following foods: (*a*) whole wheat flour, (*b*) white flour, (*c*) enriched white flour.
16. Write what you know of the dark stain that forms in an aluminum cooking vessel.

PROJECT

Pasteurization of Milk. Thoroughly sterilize two bottles by immersing them in boiling water for 15 minutes or so. Seal each bottle with absorbent cotton and put them aside to cool.

Pour about 400 cc of raw unpasteurized milk into a beaker. Pour some water into a one-liter beaker and place the beaker on a tripod. Now suspend the beaker containing milk in the one-liter beaker by means of a ring and stand. In this way the water acts as a water boiler for the milk. Place a thermometer in the milk and, using a Bunsen burner, heat the water in the large beaker. Stir the milk with the thermometer. Try to keep the temperature of the milk steady at 62° C. (or 145° F.) for about half an hour.

Pour the pasteurized milk into one of the sterilized bottles, and 400 cc of raw unpasteurized milk into the other. Seal the bottles with absorbent cotton. Cool both bottles of milk by placing them in cold water for half an hour or so.

Now place the bottles on some convenient shelf. Examine the milk in each bottle about every two hours. Does the pasteurized milk remain sweet longer than the unpasteurized milk?

REVIEW QUESTIONS ON UNIT II

A

1. What was the essential difference between the Greek idea and Dalton's idea of atoms of copper?
2. What is the essential difference between a scientific law and a statute law?
3. Write two definitions of an acid, one depending on ionization.
4. State the activity list of the metals.
5. Name the four products formed if sodium reacts with water and aluminum reacts with steam.
6. Write the symbols for two mono- and two divalent metals, and two mono- and two divalent non-metals.
7. Write formulas for: (*a*) zinc nitride; (*b*) silver oxide; (*c*) lead chloride (*d*) aluminum carbonate; (*e*) sodium sulfate; (*f*) ammonium nitrate; (*g*) calcium hydroxide.
8. How may (*a*) an atom be converted into a positive ion, and (*b*) a negative ion be converted into an atom?
9. By what simple test would you show the presence of hydroxide ions in a solution?
10. What is meant by (*a*) a carbohydrate, (*b*) a

hydrocarbon? Give an example of each and write the formula.

11. State which of the following substances occur in nature and which are entirely synthetic: (*a*) sugar; (*b*) paper; (*c*) soap; (*d*) rubber; (*e*) plastics; (*f*) explosives.

12. Write the structural formula for: (*a*) octane; (*b*) ethylene.

13. What are vitamins? Name a good source of vitamin C.

B

14. State the Law of Conservation of Mass and explain why this is a basic concept in theoretical chemistry.

15. Explain why the "ionization" definition of an acid is preferred to the definition that makes no reference to ionization.

16. By means of ionic equations explain the difference in activity of the metals aluminum and copper with dilute sulfuric acid.

17. Write balanced equations for the following reactions:
- (*a*) magnesium and steam
- (*b*) iron and hydrochloric acid
- (*c*) sodium carbonate + calcium hydroxide → sodium hydroxide + calcium carbonate
- (*d*) ammonium sulfate + copper nitrate → ammonium nitrate + copper sulfate.

18. Write equations to illustrate combination and decomposition reactions.

19. Describe an experiment you would perform to prove whether or not the solute of a solution is an electrolyte.

20. What is (*a*) a strong acid, (*b*) a weak acid? Give an example of each and state how you could distinguish between them.

21. Explain the process of copper plating.

22. Compare the roles played by (*a*) nature, (*b*) the chemist in the manufacture of sugar and soap.

23. Name an important nitrogen compound that cannot be synthesized, and one that can. What is meant by the term *fixation of nitrogen?*

24. What is meant by *cracking?* Why is this an important industrial process?

25. What is the difference in food value between a carbohydrate and a protein? Name a good source of each food.

26. What are bacteria? In what respect are they (*a*) harmful, (*b*) beneficial?

27. Explain why it is necessary to protect the consumer by a Food and Drug Act.

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Unit 12

THE UNIVERSE

58. THE SUN
59. THE SUN'S FAMILY
60. COMETS, METEORS, AND THE MOON
61. BEYOND THE SOLAR SYSTEM
62. ENERGY FROM ATOMS
63. CHEMICAL AND NUCLEAR ENERGY

Chapter 58

THE SUN

In earlier chapters we have seen how important the sun is to us. Without the light and heat of the sun there would be no life on the earth. The most vital of all chemical reactions is photosynthesis, which depends on light. Without sunlight plants cannot make chlorophyll; and without chlorophyll they cannot make starch and sugar, which are the main foods of both plants and animals. In other words, if there were no sunlight, there would be no vegetation, and without vegetation animal life could not exist on the land or in the sea. Sea life, both plant and animal, is the source of petroleum; thus without sunlight we would have no natural sources of gasoline.

The production of food and petroleum are not the only important results of photosynthesis. All plant cells have a membrane of cellulose. This is also true of trees, where the cellulose forms the hard woody structure. Without sunlight there would be no cellulose; without cellulose there would be no trees; without trees there would be no coal; without coal and oil our modern civilization could not have developed.

Thus we see that life on the earth depends on the *light* of the sun; but the *heat* of the sun is as necessary to life as the light. Without the sun's heat there would be no evaporation from rivers, lakes, and seas. Without evaporation there would be no rainfall, and without rain there would be no water for the crops of the earth. Indeed, without the sun the temperature of the whole earth would be so low that all rivers, seas, and lakes would be solid ice.

If the earth's surface were not heated by the sun, there would be no winds, for winds are convection currents formed by the uneven heating of the earth's surface. Without winds there would be no circulation of water vapor, which is another essential factor in sustaining life on earth.

Thus we see that the sun's light and heat are essential to life on earth.

ANCIENT ASTRONOMY

Throughout the ages man has been fascinated by the sun. The study of the heavenly bodies, including the sun and the earth, is known as *astronomy*. It was the first of the sciences to be studied by man.

We know from historical records that thousands of years ago people worshiped the sun. Its daily appearance on the eastern horizon at daybreak, its regular course across the sky through the day, and its setting on the western horizon were observed by early man. Probably the oldest records of religious worship now in existence are huge stones in Brittany, France, and at Stonehenge in England. They show that men of the New Stone Age observed the motions of the sun, and with those observations they measured time.

Early man believed that the sun and the stars were moving past him. He had no means of knowing that he was on a planet that was moving because he could not see the earth moving. You can put yourself in a similar position if you imagine that you are in a train alongside another train at a railroad platform. One of the trains starts to move. Assuming that you cannot feel the motion, how do you find out which train is moving? If you could not look at the platform, which you know is stationary, could you tell whether your train or the other train is moving? Similarly, primitive man had no evidence to judge by and he made the wrong guess.

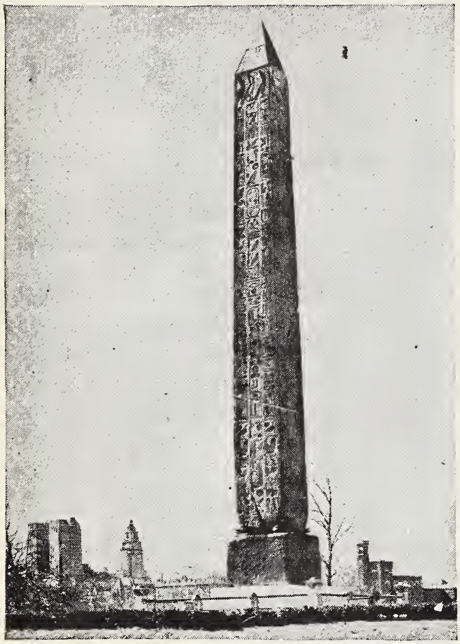

Courtesy New York City Park Dept.

Fig. 58–1. This obelisk from Alexandria, Egypt, is called Cleopatra's Needle and is now in Central Park, New York. It is typical of the obelisks that were the clocks and calendars of the early Egyptians. Its shadow moves with the sun's path and lengthens and shortens with the seasons.

Egyptian Astronomy. The ancient Egyptians knew many astronomical facts. Their obelisks, some of their temples, and even some details of the construction of their pyramids, show that their positions are linked to that of the sun at a definite time of the year. An obelisk, such as Cleopatra's Needle (Fig. 58–1), was used primarily as a sundial. The obelisk, or shadow clock, and the pyramids were among the earliest calendars.

Greek Astronomy. The Greeks had a more poetic concept of the sun than the Egyptians. To them the sun was the fiery golden carriage of the god Apollo racing across the sky. However, a Greek philosopher named *Aristarchus* proposed the theory that the *sun,* and not the earth, was the center of the universe. He believed that the earth revolved about the sun in a circular orbit; that the earth was just a *planet,* or "traveler," that received its warmth from the sun. But few people agreed with Aristarchus. The accepted theory of the time was announced by *Aristotle,* one of the greatest of the Greek philosophers. Aristotle maintained that the earth was fixed and immovable, and that the sun and the other heavenly bodies moved around it. So great was Aristotle's influence that this false theory was held for nearly two thousand years.

The Egyptian astronomer *Ptolemy,* basing his views on those of Aristotle, devised a complete theory of the universe with the earth as an immovable sphere at its center. He said that the sun, moon, and stars rose in the east and set in the west because they moved in circles around the earth. The earth must be a fixed body, he wrote, because otherwise the loose things on it, including the air, would be left behind. This theory was not challenged until the 16th century.

ASTRONOMY IN THE 16th AND 17th CENTURIES

Copernicus. In the 16th century a Polish astronomer named Copernicus revived Aristarchus' ideas and supported them with observations and reasoning. At that time telescopes had not yet been invented. Copernicus therefore found another means of observing the heavens. He cut slits in the walls of his house in such positions that he could watch a few stars over many nights. He noticed that the brightness of the planet Mars varied considerably. Because of these variations Copernicus could not believe that heavenly bodies remained at fixed distances from the earth. He explained the movement of these heavenly bodies by supposing that once in 24 hours the earth rotates in a direction opposite to the apparent motion of these bodies. On this basis Copernicus discarded the idea that a gigantic universe revolved about the earth. Moreover, he recognized the earth as a part of the sun's system and distinguished the sun's system from the stars. He produced evidence that the sun is the center of the solar system and that the planets revolve around the sun and rotate about their own axes.

Courtesy Bausch and Lomb Optical Co.

Fig. 58–2. A painting of Galileo demonstrating his first telescope from the tower of St. Mark's in Venice.

Galileo. Early in the 17th century Galileo, the famous Italian scientist, mathematician, and astronomer, made the first astronomical telescope. It was a small spyglass that could be carried about. Although the diameter of its lens was only 2½ inches, it permitted Galileo to see 100,000 stars that had never been seen before.

Galileo turned his telescope toward Jupiter and, to his amazement, discovered four of its moons. Moreover, from their positions on successive nights, he noticed that the moons were revolving around Jupiter. This observation disproved Aristotle's theory that all heavenly bodies revolved about the earth. From many other observations Galileo concluded that Copernicus' theory was correct, and he strongly supported it.

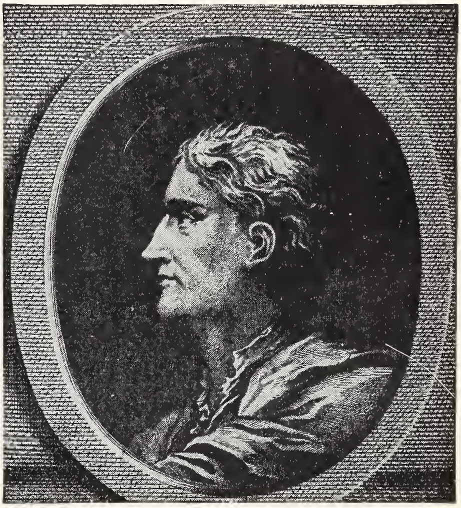


Fig. 58–3. Sir Isaac Newton (1642–1727), astronomer, physicist, and mathematician.

By supporting the theory that the sun, and not the earth, is the center of the universe, he opposed the accepted views of his time. His writings were banned by the Church; he was brought to trial and spent some time in prison.

Newton. One of the outstanding contributions to astronomy was made in the 17th century by the English physicist Sir Isaac Newton. Newton made the first *reflecting* telescope. It was only 6 inches long, but it magnified objects 40 times. The concave mirror in this telescope, made of an alloy of copper and tin, gave a very clear image. The significance of Newton's contribution to the science of astronomy is apparent when we realize that the giant telescopes of modern science are of this reflecting type.

MODERN ASTRONOMY

Today the many accessories attached to a large telescope have made it one of the most versatile of all instruments. For instance, a spectroscope attachment enables the astronomer to determine the chemical elements present in the source of light, the temperature of this source, and its speed of motion through space. The spectroscope has been the key to the solution of a number of astronomical mysteries.

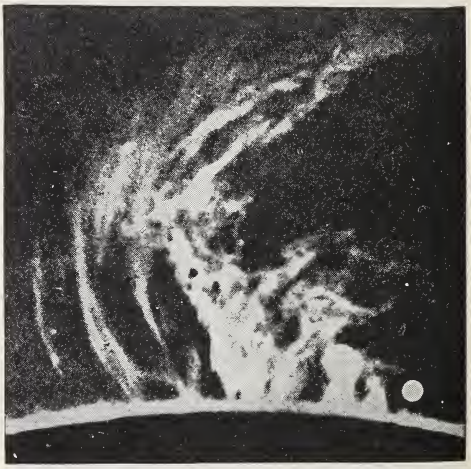
The effect of the sun on weather and on radio communication is now being investigated by means of electronic devices which register data either on the ground or aloft in rockets and balloons. In this way scientists discover new information about the ionosphere, which is strongly affected by the sun's radiation.

Another astronomical aid is the photographic plate. As explained in Chapter 42, astronomical telescopes are really cameras; that is, the stars are not observed directly by the naked eye but are photographed. By this method millions of stars too faint to be seen by the eye are recorded by astronomical telescopes.

These tools have expanded the astronomer's view of the universe. They have enabled him to locate our sun in space, and not only to study our immediate neighbors, the planets, but also to identify suns so far away that their light takes thousands of years to reach us.

STRUCTURE OF THE SUN

The sun is a sphere of hot gases whose diameter is 864,000 miles. In spite of its calm appearance, even through a low-power telescope, we now know that this mass of gases and vapors is in constant motion. Violent eruptions take place near the surface, hurling out gases at 25,000 miles per hour. Some of these flaming gases appear on the edge of the sun, spouting up thousands of miles above its surface, as shown in Fig. 58–4.



Mount Wilson Observatory

Fig. 58–4. A solar prominence which extends almost 150,000 miles beyond the sun's surface. The small white circle indicates the relative size of the earth.

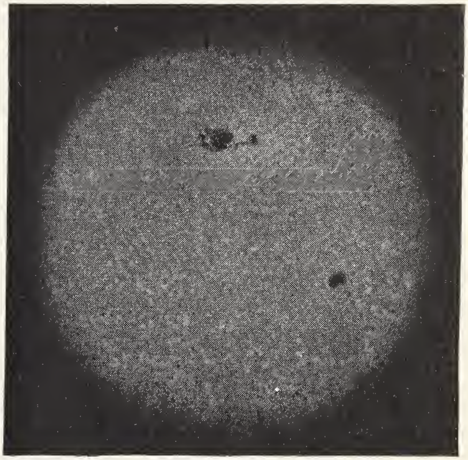
The Sun's Temperature. Astronomers now believe that the temperature of the surface of the sun is about 6000° C. and that the temperatures inside the sun range from 15 to 30 million degrees. We cannot imagine such high temperatures; but for purposes of comparison it may be stated that the temperature of the filament of an ordinary 150-watt light bulb is about 3000° C. An idea of the amount of heat radiated from the sun's interior may be gained from the following comparison. If a coin the size of a quarter could be heated to the temperature of the interior of the sun, the radiation from it would kill every living plant and animal within a thousand miles. Probably the nearest approach to solar temperature was the terrific blast of the atomic bomb dropped on Hiroshima in 1945. In this explosion metal pieces were turned into vapor, as was the steel tower in the experimental blast in New Mexico earlier that year.

Because of the extremely high temperatures *all the substances on the surface of the sun must be in a gaseous state.* The elements sodium, calcium, iron, lead, and silver, for example, are present as vapor. The gases hydrogen and helium are also present. There are no compounds in the sun because at such high temperatures the bonds that hold the atoms in a molecule are broken. Even if it were possible for a molecule of water to form in the sun, it would be instantly split into hydrogen and oxygen atoms. And many of the atoms themselves are broken up so that electrons are stripped from the nuclei; thus in the center of the sun there may be only electrons and nuclei whirling about at incredible speeds.

Sunspots. Scattered intermittently on the sun's surface are dark patches called *sunspots.* Sunspots are sometimes observable without a telescope. They may be so large that the earth placed inside one would look like a Ping-pong ball inside a bucket. If you want to look for sunspots, be sure to use heavily smoked glasses; protection of your eyes is absolutely essential.

Sunspots appear dark because they are cooler than the rest of the sun's surface. They are thought to be gas that has risen from the sun's interior, expanded at the surface, and cooled. Even a small telescope shows that the spots move across the disk of the sun, gradually changing in size and structure. This indicates that the sun rotates around its axis, taking about twenty-five days for one full rotation.

The study of sunspots is of great help to astronomers and radio-communication engineers. It is generally believed that sunspots, especially the large ones, cause electrical disturbances on the earth, affecting telephone, telegraph, and radio transmission. Sunspots also cause beautiful displays of aurora borealis, or northern lights, in the night sky.



Mount Wilson Observatory

Fig. 58–5. A direct photograph of the sun, taken in January, 1926, showing the largest group of sunspots ever photographed. The pointers indicate the sun's axis of rotation.

The Sun as a Source of Light. Finally, let us consider the sun as a source of light. You will remember from Chapter 40 that the intensity of a source of light is measured in candle power (c.p.). The intensity of the headlight of an automobile, for example, is usually 32 c.p. The intensity of the sun's light has been measured and found to be millions of millions of candle power. Actually, of course, a relatively small fraction of the light from the sun reaches us because the light is radiated in all directions. Nevertheless, without that fraction every living thing on the earth would perish.

When we refer to such things as temperature, pressure, or candle power in connection with the sun, the values are so high that they are beyond our imagination. In fact, the adjective *astronomical* is used to describe properties that are far beyond the realm of our experience. In Chapter 59 we shall find that this is true also of distances in outer space.

THINGS TO REMEMBER

Early *astronomical knowledge* was a combination of observations by the unaided eye and a great deal of imagination.

Copernicus, a Polish astronomer, stated that the sun is the center of our planetary system.

Galileo made the first telescopic observations of the skies and discovered four of Jupiter's moons.

Newton invented the reflecting telescope, which is the basis of many modern telescopes.

The *spectroscope* and *camera attachments* have increased the uses of the telescope and therefore our knowledge of astronomy.

The *sun* is an enormous mass of gases and vapors in continuous turmoil.

The *surface temperature of the sun* is about 6000 ° C.; the inside temperature of the sun is estimated at between 15 and 30 million degrees.

Sunspots are cooler places on the surface of the sun.

QUESTIONS

A

1. What was the probable use of the obelisk in Egypt?

2. What is the meaning of the word *astronomy?*

3. What is the surface temperature of the sun? What is the estimated temperature of the center of the sun?

4. Give a few facts about Copernicus.

B

5. What are sunspots? What conclusions can be drawn from the study of sunspots?

6. What were the views of Aristarchus, Aristotle, and Ptolemy on the solar system?

7. Who were the following and what did they contribute to the science of astronomy: (*a*) Galileo; (*b*) Newton?

PROJECTS

1. *Visiting an Astronomical Observatory.* A visit to an astronomical observatory will tell you much about astronomical scientific methods. Little observation is done through the telescope with the eye; almost all research is based on a patient accumulation of data obtained from photographic plates. Find out in advance whether any special activities are scheduled.

2. *Visiting a Planetarium.* Some cities in the United States have a remarkable instrument called a planetarium, which shows a great number of astronomical phenomena in a short period of time. Such instruments appear to speed up time or roll time backward. In the planetarium the motions of stars, the tracks of planets, and the phases of the moon may be shown for any time of the year—past, present, or future.

Chapter 59

THE SUN'S FAMILY

Perhaps you have wondered how our earth came to be formed. Like the other planets, it was once a part of the sun. How did it become a separate body whirling on its own axis? We do not know the positive answer to this question, but scientists have enough evidence to make some intelligent guesses. The conclusion that best fits the evidence is called the *tidal theory*.

The Tidal Theory. According to the tidal theory, approximately two billion years ago a star came close enough to the sun to disturb it. We can best picture what happened by imagining that we are watching the sun's surface from a rocket ship. A distant bright star approaches the sun, traveling thousands of miles an hour. This goes on for centuries, since the distances between the stars are incredibly great. Eventually the star passes on one side of the sun and almost collides with it. As it passes the sun—and remember that the diameter of the sun is almost 900,000 miles—a gigantic bulge, thousands of miles high, seems to be forming on the sun's surface. This great bulge moves across the face of the sun following the path of the star. What is causing this elevation of the sun's surface? To answer this question, we must recall Sir Isaac Newton's Law of Gravitation: *Every body attracts every other body in the universe.* The attraction between the earth and the moon is an example of this law. The attraction between the passing star and the sun is similar to that between the earth and the moon.

As the star gets nearer to the sun its force of attraction is so strong that finally its pull on the bulge is greater than the backward pull of the sun. We can see the bulge of fiery gases being drawn from the sun. It is following the trail of the star. The star's attraction, or pull, has torn an enormously long column of gas from the sun. Now, out in space the gas is cooling and condensing to enormous drops. It is forming nine planets and their moons. These huge drops have not escaped from the sun entirely, however; they are carried away from the sun, but they revolve around it in nearly circular orbits. They have become part of the sun's family. This explanation of the origin of the planets is known as the *tidal theory* because the attraction of the sun and the passing star resembles the attraction of the earth and the moon, which causes the tides.

The Dust-Cloud Theory. Another theory to explain our solar system states that our universe was made from gigantic clouds of dust and gas that are known to exist in space, and that the sun and the planets were all formed at the same time from the same cloud of dust. This is known as the *dust-cloud theory*.

What caused the dust particles to unite with each other? According to the dust-cloud theory, the particles were pushed together by the pressure exerted by the light of the stars. In this way the particles were pressed close enough for gravitational forces to be effective, and thus they attracted one another. The

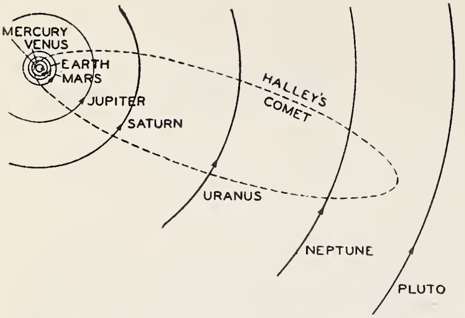


Fig. 59–1. Diagram of the solar system including the path of Halley's Comet.

cloud then contracted faster and faster; as the particles gravitated toward the center they began to rotate in a spiral. Eventually the center of the cloud condensed to form the sun, and the smaller spiraling masses, out in space, condensed to form the planets.

Thus, according to the tidal theory, the sun is the parent of the solar system; according to the dust-cloud theory, sun and planets originated independently from a common source.

THE PLANETS

There are nine known planets. The six nearest the sun—Mercury, Venus, Earth, Mars, Jupiter, and Saturn—are the brightest and have been known since early times. Because of their great distance from the sun, the three outermost planets are faint and were not discovered until comparatively recent times: Uranus in 1781, Neptune in 1845, and Pluto in 1930. The planets nearer the sun are brighter because planets shine only by reflecting the sun's light.

Each planet rotates around its axis, the periods of rotation varying from a few hours to 90 days. And all the planets revolve around the sun in the same direction in elliptical orbits. The time taken by each planet to travel around the sun is called its *year*. The length of the year is different for each planet. For example, Mercury's year is equal to 88 of our days, whereas Pluto's year is equal to 250 of our years.

The planets do not revolve around the sun at the same speed. The nearer a planet is to the sun, the greater its gravitational attraction to the sun, and therefore the greater the speed of its revolution. The speed of the nearer planets must be greater to counteract the greater pull of the sun. If the nearer planets did not travel at exceedingly high speeds, they would be drawn back into the sun.

The earth travels around the sun in an almost circular orbit. Scientists have calculated the radius of this orbit—that is, the distance from the earth to the sun—to be 93,000,000 miles. The diameter of the orbit is therefore 2 × 93,000,000, or 186,000,000 miles. Using the algebraic formula πd for circumference, we can find the length of the earth's

	Distance from Sun (millions of miles)	*Diameter (miles)*	*Length of Year*
Sun		864,000	
Mercury	36	3,100	88 days
Venus	67	7,600	225 days
Earth	93	7,900	365.25 days
Mars	141	4,300	1.88 years
Asteroids	200–300	1,300	1.75 to 13 years
Jupiter	483	87,000	11.86 years
Saturn	886	72,000	29.50 years
Uranus	1,782	32,000	84 years
Neptune	2,800	31,000	165 years
Pluto	3,700	4,000	250 years

orbit: 3.14 × 186,000,000 = 584,000,000 miles.

We know that the time the earth takes to complete its orbit is one year, or 365¼ days. Multiplying 365¼ by 24, then by 60, then by 60 again, we find that there are approximately 32,000,000 seconds in a year. The velocity of the earth's revolution around the sun is therefore $\frac{584,000,000}{32,000,000}$, or 18.5 miles per second.

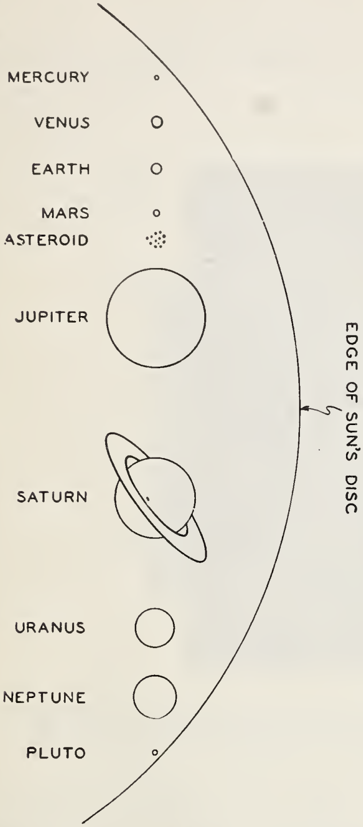


Fig. 59–2. Approximate sizes of the planets compared with the sun.

Mercury. Mercury, besides being the smallest of the planets (it is not much larger than our moon), is the planet nearest to the sun. It was called Mercury by the ancient astronomers because, according to Greek legend, Mercury was a close friend of Apollo, the sun god. The relative nearness of Mercury to the sun interferes with our observation of the planet. Because it is always nearer the sun than is the earth, we cannot see it at night; it is visible only just before dawn or in the early evening.

Because of its nearness to the sun, one half of Mercury always faces the sun, the other half never turning toward it. The result is that the face toward the sun becomes exceedingly hot—about as hot as molten lead. The face away from the sun becomes exceedingly cold—about as cold as dry ice. Mercury rotates once on its axis each time it revolves around the sun.

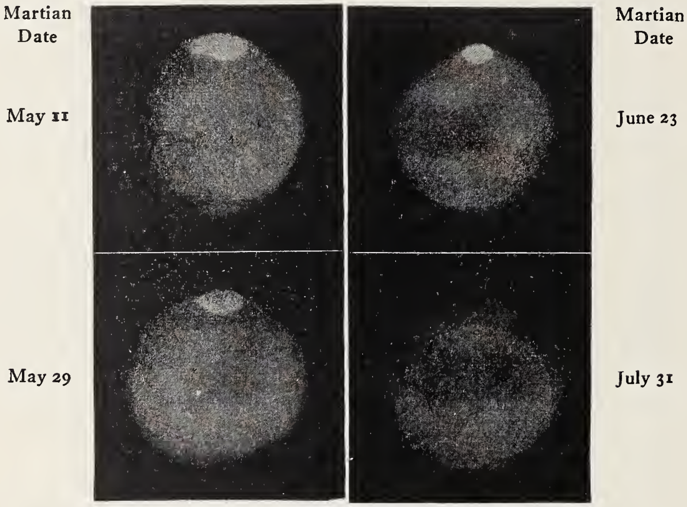
Mercury has no atmosphere, probably because it does not have sufficient gravitational attraction to hold an atmosphere. Because it has no atmosphere and because it always presents the same face to the sun, Mercury is like the moon, except that the moon is in the gravitational grip of the earth. Without an atmosphere life cannot exist either on Mercury or on the moon.

Venus. Venus is the next-distant planet from the sun and the nearest to the earth. It is about the same size as the earth. Except for the sun and moon, Venus is usually the most brilliant object in the sky. At its greatest brilliance it is sometimes plainly visible during the day. Because it is between the earth and sun, Venus, like Mercury, is most often seen in the morning or the evening.

Telescopic observation shows that Venus is covered with a dense atmosphere, which prevents study of its physical features. The spectroscope reveals that there is little or no oxygen but a great deal of carbon dioxide. The absence of oxygen means that Venus has no life as we know it, and it is generally believed that life does not exist on that planet.

Mars. The planet next farther away from the sun than the earth is Mars, which is almost as brilliant in the sky as Venus. Mars has a diameter about one-half that of the earth.

The temperature of Mars has been carefully studied, particularly because there is some possibility that life exists on this planet. Telescopes concentrate both light and heat rays, and sensitive instruments attached to telescopes enable astronomers to measure the temperature of planets with considerable accuracy. Thus we know that the temperature of Mars is lower than that of the earth; the maximum summer temperature is probably not higher than from 40° F. to 50° F. The outer planets are very cold. Jupiter is too cold to support life, and the planets beyond Jupiter have temperatures far below anything we experience on earth.



E. C. Slipher from Lowell Observatory

Fig. 59–3. This series of photographs shows the seasonal changes on Mars. Notice the shrinking of the polar cap and the growth of the dark areas (the green belt) as the summer season advances.

A distinctive feature of Mars is its red color. This is probably the color of a mineral oxide. The minerals are thought to have combined with the oxygen in its atmosphere, which may be forming a vast desert that covers about 60 percent of the surface of the planet. There is, perhaps for this reason, little oxygen in Mars' atmosphere. Patches of green, perhaps plant growth, can also be seen.

There are also snowcaps and a regular network of markings. During the winter two snowcaps appear around the poles; during the summer they disappear, probably because the snow melts. Some astronomers maintain that the markings are artificial canals built to convey water for irrigation purposes. There are no oceans on Mars, and there is less water vapor in its atmosphere than in ours. Canals to carry water from the melting snows to support plant life are, therefore, a logical supposition. However, to be observed by a telescope 50,000,000 miles away, the canals would have to be at least ten miles wide. This makes the canal theory somewhat doubtful.

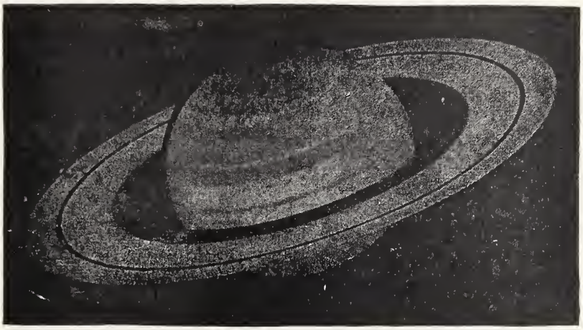
However, the atmosphere, the temperature range, and the canals suggest the ever-perplexing questions, Is there life on Mars? Are there Martians? Although the climate, from our point of view, is cold and forbidding, it is possible for some forms of plant life to exist in it. The general opinion among astronomers is that plant life probably does exist and that it is remotely possible that there are also some forms of animal life.

The Asteroids. Asteroids are very small planets made up of little chunks of rock whirling in space like the large planets. There are more than a thousand of them. Their diameters vary from a few miles to about 300 miles. Little is known about their origin, but they appear to be fragments of a satellite torn apart by gravitational stresses. They can be seen only with a telescope.

Jupiter. Jupiter is larger than all the other planets combined. Most of the planets have *satellites,* or moons. Usually the larger the planet, the more moons it has. Jupiter has at least eleven. The four largest moons can be seen easily with binoculars. It is supposed that moons are fragments torn from the planets, formed in much the same way that planets were probably torn from the sun. Jupiter's atmosphere contains a high proportion of methane. Its temperature is about −200° F., which means that life is impossible there.

Saturn. Saturn, next to Jupiter in size, is particularly interesting because of its satellites. It has nine moons, and, in addition, three flat circular rings that look something like the brim of a straw hat. These rings, first observed by Galileo, are composed of millions of tiny solid bodies. They may have once been a moon that disintegrated.

Uranus, Neptune, and Pluto. Uranus, the seventh planet from the sun, was discovered by William Herschel, an English astronomer, in 1781. It can barely be seen with the unaided eye. A powerful telescope is needed to see Neptune and Pluto, which are otherwise far beyond the limits of visibility. We will discuss Neptune and Pluto again (next page).



From a drawing by Keeler. Lick Observatory

Fig. 59–4. Saturn.

THE SOLAR SYSTEM

What makes astronomical discoveries possible? Underlying all work on planets are the Law of Motion and the Law of Gravitation discovered by Sir Isaac Newton. The Law of Motion states: *If an object is set in motion, it will continue moving forever in a straight line unless it is acted upon by some outside force.* In other words, if a hard metal ball were set in motion on a perfectly smooth surface, it would continue to roll in a straight line forever if it were not for the small amount of friction between the ball and the surface. The greater the friction the sooner the ball will stop. In outer space, where the planets and stars move, friction is practically nonexistent. These bodies would therefore move forever in a straight line if there were no other force acting on them.

Why do the planets move in curved paths? The answer to this question is essentially the same as the answer to the question, Why does an apple fall to the ground? You have learned that it was the observation of the falling apple that led Newton to the discovery of the Law of Gravitation, which states: *Every body attracts every other body in the universe.* This attraction depends on the amount of matter in each body; that is, the greater the mass the greater is the attractive force. Hence, if we were to consider as a pair the earth and the sun, we could say, by the Law of Gravitation, the sun attracts the earth just as the earth attracts the sun. However, the earth is so much smaller than the sun that its motion is more affected by the sun's attraction than is the sun by the earth's attraction.

You can demonstrate the motion of a planet around the sun by whirling above your head a weight attached to the end of a string. In this illustration you correspond to the sun and the weight corresponds to the earth. As the weight is moved, your hand exerts an inward pull on the string. This pull corresponds to the gravitational attraction of the sun on the earth. If you suddenly release the string, the weight flies off at a tangent to the circle, according to the Law of Motion. The earth moves in a similar way. Its curved path is a compromise between the direction due to the Law of Motion and the direction due to the Law of Gravitation. Astronomers can predict with exactness not only the path taken by every planet but also the paths of comets around the sun and the paths of the shadows of eclipses across the face of the earth.

The Discovery of Neptune and Pluto. The laws of motion of the planets enable astronomers to predict the time at which a planet will be at a definite place. Any irregularity in the motion of a planet indicates that some other body is disturbing the motion. In fact, it was such irregularities that led to the discovery of Neptune and Pluto.

Almost a century ago Uranus was the outermost planet known. Its orbit was well determined, but some irregularities in its course led astronomers to suspect the existence of a disturbing body. Two astronomers, Leverrier of France and Adams of England, independently determined the position where such a body must be in order to deflect Uranus from its calculated position. Leverrier requested Galle, at the Berlin observatory, to search within a circle of one-degree radius this part of the sky. Almost exactly at the spot predicted the new planet Neptune was discovered.

Neptune's orbit was also disturbed in its calculated course, which led scientists to believe there was still another planet. Percival Lowell, at Flagstaff, Arizona, made his calculations and began his search. He died before a successful search was completed. But in 1930 Pluto was found on photographs of the region where Lowell had forecast its discovery. Pluto was named after the god of darkness because it receives so little light from the sun.

THINGS TO REMEMBER

The most likely theory of the origin of the planets appears to be the *tidal theory;* a star passing too near our original sun tore out a mass of gases that was broken into smaller masses to form the planets and their satellites.

The *sun's family* is made up of nine principal planets of different sizes and more than a thousand asteroids.

All planets and their satellites *shine by reflected light* from the sun.

The course of every planet (and of every satellite) is an *elliptical orbit.*

QUESTIONS

A

1. Why do we call the generally accepted theory of the origin of the planets the tidal theory?

2. List the principal planets, and for each planet state one or two main characteristics.

3. Which planets are nearer to the sun than the earth?

4. Which planets are outside the earth's orbit?

5. State the two physical laws that explain the motion of the planets round the sun.

6. Explain why there is no atmosphere on the planet Mercury.

B

7. Give a brief account of the tidal theory of the origin of the planets.

8. Write a brief account of the dust-cloud theory.

9. Could there be life on Mars? Explain.

PROJECT

To Make a Model of the Solar System. In order to get a good idea of the relative sizes and distances of the planets, imagine the following fairly accurate model of the solar system. Or, better still, lay out part of the model on the school ground or in some other open area.

If the sun is represented by a basketball, *Mercury* would be half as big as a pinhead 40 feet away. On this scale the dimensions of the remaining planets would be *Venus* as large as an apple seed, 80 feet from the sun; *Earth,* same size as Venus, 110 feet from the sun; *Moon,* one-third of a pinhead, 3.5 inches from the Earth; *Mars,* a small apple seed, 160 feet from the sun; *asteroids,* specks of dust to fine sand, 250 to 350 feet from the sun; *Jupiter,* a Ping-pong ball, 560 feet from the sun; *Uranus,* a marble ⅖ mile from the sun; *Neptune,* a marble ⅗ mile from the sun; *Pluto,* a small apple seed, ⅘ mile from the sun. The nearest star would be a basketball, 5,000 miles away.

Chapter 60

COMETS, METEORS, AND THE MOON

Comets. The appearance of a comet in the sky was once regarded as an omen of impending disaster. Large ones, like Halley's Comet, that can be seen with the naked eye, are unusual occurrences; generally comets can be seen only with a telescope.

Comets are composed of gases at extremely low pressure and of dust particles that are sometimes as large as a pea or a walnut. They may be as large as 10,000 miles in diameter at the head, or nucleus, and the tails may stretch out for several million miles. As the comet approaches the sun, the sun's radiation exerts enough pressure to force gases out of the center nucleus to form the tail. The tail therefore always points away from the sun. As the comet approaches the sun, its tail is behind; as it leaves the sun, its tail is in front. Like other members of the solar system, comets move in elliptical orbits. They approach the sun with increasing speed until they get as near as their orbit allows; then they move away with decreasing speed as they pass farther and farther into space.

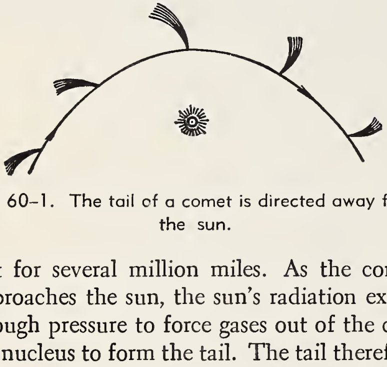
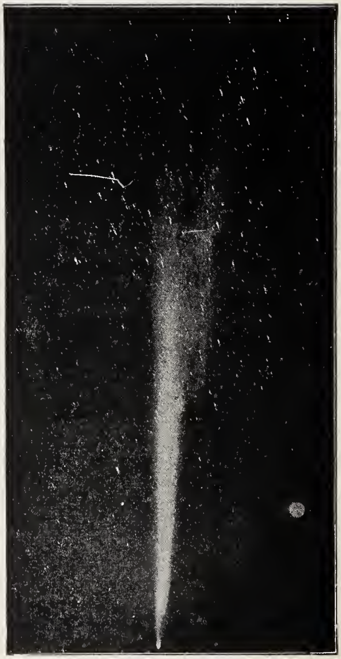


Fig. 60-1. The tail of a comet is directed away from the sun.

Halley's Comet has appeared with great regularity every seventy-six years. Some of its recorded appearances are among the oldest astronomical observations. The British astronomer Halley observed this great comet in 1682, calculated its orbit, and predicted its return in



Lowell Observatory

Fig. 60-2. Halley's Comet, photographed before dawn on May 13, 1910. The bright object on the right of the photograph is the planet Venus.

1757. This was the first prediction of a comet's return. The most recent appearance of Halley's Comet was in 1910, when the earth actually passed through its tail without noticeable effect. A comet's tail, which is usually several million miles long, is so thin that we can look through it and see the stars without interference. See Fig. 59–1.

Meteors and Meteorites. Some comets have literally been torn to pieces and have disappeared completely. In their places showers of *meteors* (often miscalled shooting stars) have appeared. It is now almost certain that some meteors are remnants of comets. Meteors are usually about the size of a pea. However, they travel at speeds of between 30,000 and 160,000 miles an hour. They are invisible until they enter the upper layers of our atmosphere. At heights of from 20 to 80 miles above the earth the air is dense enough so that friction with the atmosphere raises the temperatures of meteors by thousands of degrees and almost always burns them up. Rarely does a meteor reach the earth's surface before it is completely consumed. A meteor found on the earth is called a *meteorite*. Most meteorites are stony; others are iron. Some rare ones contain nickel or traces of platinum.

The largest meteorite to fall in the United States struck with explosive violence in the Arizona desert area approximately fifty thousand years ago. This meteorite must have weighed more than ten million tons, and it hit the earth at an estimated speed of 150,000 miles an hour. The crater it formed is nearly a mile wide and 600 feet deep.

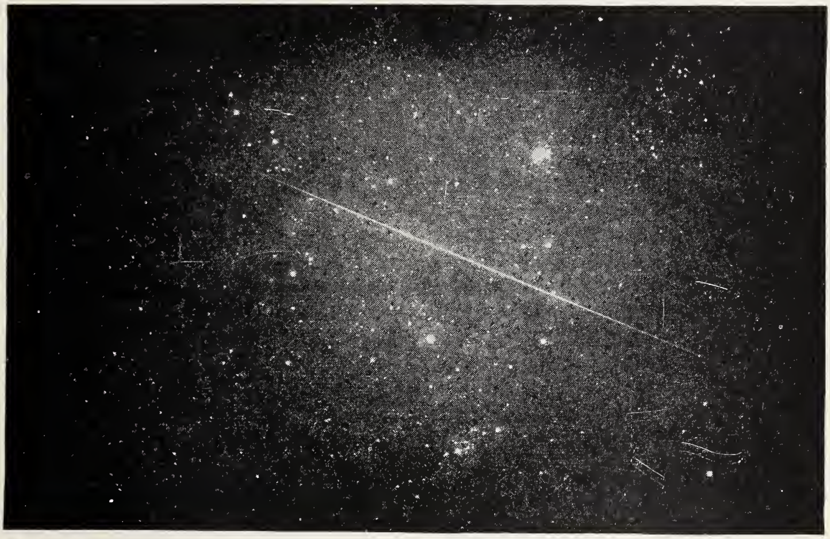


Photo from Oak Ridge Station of Harvard Observatory

Fig. 60–3. Trail of a meteor. The star cluster, behind the meteor, shows by contrast the brilliance of the meteor.

THE MOON

The moon is a comparatively small body, only about 2,000 miles in diameter. Yet it shines so brilliantly and seems so near the earth that it has attracted man's attention

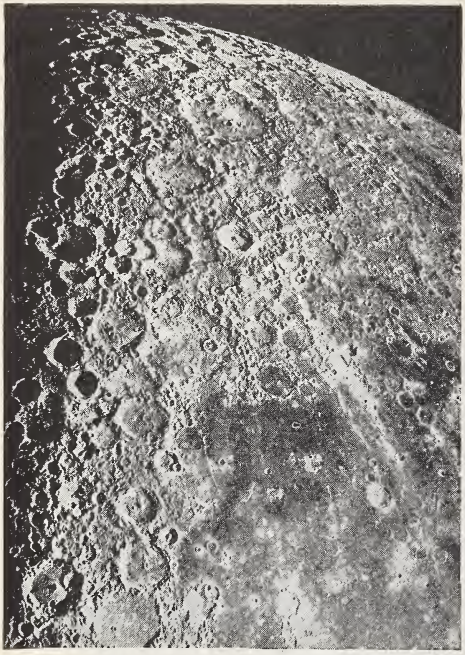


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Fig. 60–4. Southern portion of the moon at last quarter.

since the dawn of history. Since remote ages of the past, calendars have been based on the moon's revolution around the earth in 27⅓ days. The oldest Hebrew calendar and the elaborate calendar of the Mayas of Central America, for example, were based on lunar observations.

Like the planets, our satellite, the moon, shines only by reflected sunlight. The sunlight reflected by the moon is changed to a certain extent by the nature of the surface of the moon. The study of the moon's light has revealed that the surface of the moon is covered by thousands of craters. The origin of these craters is obscure, but it probably is volcanic.

Like the earth, the moon has two kinds of motion; it *rotates* on its axis and it *revolves* around the earth. The time consumed in one rotation is the same as the time taken for one revolution, namely 27⅓ days, which means that the moon always keeps the same side of its bulk toward the earth. Man therefore does not know what the other side of the moon looks like. Its motion relative to the earth and the sun makes it appear in different forms, or *phases*, such as full moon, half-moon, crescent and waning moon, at different times of its rotation. A project at the end of the chapter illustrates the different phases of the moon in the course of one revolution.

Conditions on the Moon's Surface. There is no atmosphere on the moon because its gravitational attraction is too small to hold one. The absence of atmosphere and water makes the moon a far different place from the earth.

If we could travel to the moon by rocket, what would we find there? We would see both sun and stars, even by day, in a black sky. The stars would appear brighter than they appear when seen from the earth, and we would be able to see more of them. How do

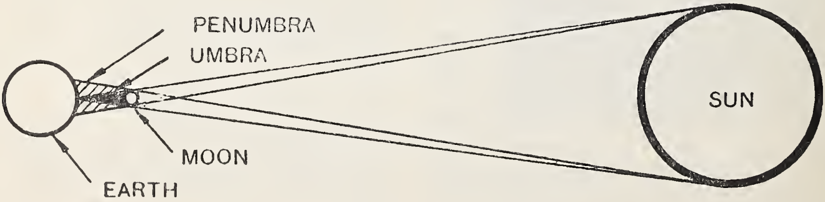


Fig. 60–5. A solar eclipse.

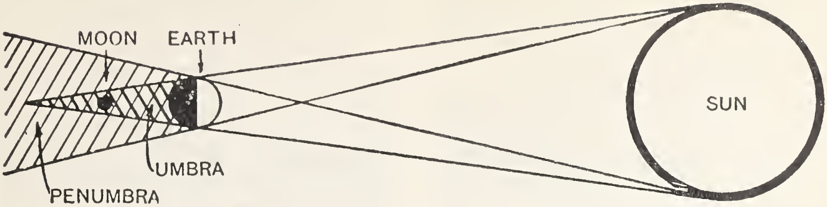


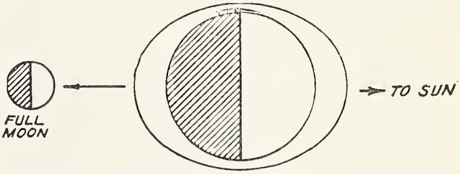
Fig. 60–6. A lunar eclipse.

we know that we would observe these things? There would be no rain or snow or fog, nor would we see any beautiful sunsets. Do you understand why?

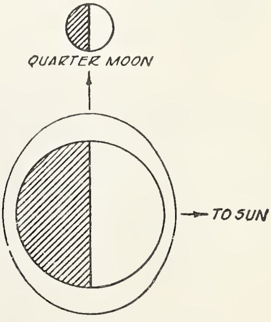
A day on the moon would last two weeks, and a night would also last two weeks. Can you explain this? During the day the temperature would rise to about 200° F. and during the night it would drop to about −200° F. And there are no sounds on the moon; not even the crash of a large meteorite could be heard. Can you explain this? The mountain peaks on the moon rise in almost vertical columns to 25,000 feet. There has been no atmospheric erosion or weathering through the ages—little to wear the jagged edges of rocks, nothing to soften the grim scene. The moon would be a frightening, fascinating place—a dead and silent world.

Eclipses. In spite of its small size the moon from time to time blocks the light of the sun from a region of the earth. This happens when the moon is passing between the sun and the earth. We then have a *total eclipse of the sun.* As the earth rotates, the region of darkness (seldom over 160 miles wide) travels across the surface of the earth as shown in Fig. 60–5. Conversely, when the earth passes between the moon and the sun, there is an eclipse of the moon (see Fig. 60–6). Then the shadow of the earth makes the pale cold light of the moon paler. When the shadow is largest, the moon turns coppery red. As the earth moves on, the moon gradually ceases to be eclipsed. An eclipse of either the moon or the sun is possible only when the sun, earth, and moon lie in the same straight line. The project at the end of this chapter will show how such eclipses occur.

Tides. The formation of tides is due to the attraction between the earth and the moon. The moon attracts the ocean, and the water piles up under the moon to form a *high tide.* Similarly, another high tide, though not so



SPRING TIDES



NEAP TIDE

Fig. 60–7. Spring and neap tides.

high, is formed on the opposite side of the earth. To allow for this piling up, the water is drawn from the sides, thereby forming *low tides* between the places of high tide.

As the earth rotates on its axis, it brings different places under the moon so that they in turn experience high tide. If the moon did not move, there would be two high tides with every rotation of the earth—that is, every 24 hours. But because the moon revolves in the same direction as the earth rotates, a place on the earth must make more than a full circle to come under the moon again. This extra rotation takes 50 minutes. Hence there are two tides every 24 hours and 50 minutes; or, stated another way, high tide occurs at intervals of 12 hours and 25 minutes.

The sun also causes tides, but because the sun is much farther away than the moon it is less effective. However, if the sun and the moon are in line, either on the same or on opposite sides of the earth, the lunar and solar attractions reinforce each other and cause very high tides, known as *spring tides*. Spring tides occur at full moon or new moon.

If, on the other hand, the sun and moon form a right angle with the earth, lower tides, called *neap tides*, are formed. Neap tides occur when the moon is in either the first or the third quarter of its orbit.

THINGS TO REMEMBER

Comets are masses of gas and dust of tremendous size and low density. They travel like planets in elliptical orbits around the sun.

Meteors are remnants of comets.

Meteorites are remnants of meteors that have not been completely consumed by the heat of atmospheric friction.

Our *moon* is a typical satellite of a planet.

The *phases of the moon* are due to the revolution of the moon around the earth.

Eclipses are due to an alignment of the sun, moon, and earth.

Tides are caused by the gravitational pull of the moon and the sun.

QUESTIONS

A

1. What is the difference between a meteor and a meteorite?

2. What is the period of revolution of the moon?

3. Compare the diameter of the moon with that of the earth.

4. What are spring tides? neap tides?

B

5. Briefly describe a comet.

6. Describe, drawing a diagram, what happens when there is an eclipse of: (*a*) the sun; (*b*) the moon.

7. Explain how tides are caused.

8. Viewed from the moon, the sky would appear black. Explain why.

PROJECT

To Prepare a Model of the Phases of the Moon. In order to study the phases of the moon, we need a source of light to represent the sun and a white ball of wood, plaster, or soap to represent the moon. Soap is particularly good because it can be easily shaped to represent the main features of the moon, which can be found in books on astronomy or in periodicals such as *Sky and Telescope*. The "moon" should be mounted on a stand. To make the light effects more striking, the room should be darkened. Cover a 25-watt bulb with a tin can (which acts as a screen), from which one end has been removed. In the side of the can cut a hole large enough for the bulb to pass through. Then place the can over the bulb with the open end horizontal.

The light is directed toward the observer. The moon is moved counterclockwise along a circular path around the observer. The observer will study the appearance of the moon in successive positions with respect to the line earth-sun. The phases—new moon, first quarter, full moon, and last quarter—will be recognized easily.

Chapter 61

BEYOND THE SOLAR SYSTEM

Have you ever watched the sky in the country on a clear autumn night? When there is no artificial light the stars seem almost close enough to touch. At such a time we wonder at the immensity of the universe. Modern astronomy helps us, perhaps more than any other science, to appreciate its majesty. The picture that the astronomer paints, though still far from complete, is continually becoming more detailed.

STARS

All visible stars (and the countless invisible ones) are suns. Some of these suns are many times larger than our sun, and others are much smaller. Probably 4,000 or 5,000 stars are visible to the naked eye, and about 100,000 can be seen with binoculars. But no astronomer has ever counted the stars, because even the most powerful telescope cannot detect the most distant ones.

Differences between Stars and Planets. One difference between stars and planets is that the planets appear to move, whereas the stars seem to be stationary. The stars really move at high speeds, but they are so far away from us that through centuries of time they seem to remain in the same position. Most of the stars still appear to be in the positions they occupied when the ancient astronomers charted them.

Through a telescope the nearer planets can be magnified to look as large as the moon. But no telescope has yet been constructed that will magnify the distant stars to anything larger than points of light. Telescopes do, however, make the stars appear brighter.

Another difference between planets and stars is the way in which they shine. The planets are solid and shine only by reflecting the light of the sun. The stars, on the other hand, are gaseous and are exceedingly hot. The light they emit is their own incandescence.

Density of Stars. The density of the material in some of the stars is so low as to be comparable to the best vacuum obtainable in a laboratory. Samples of such material would be lighter than our atmosphere. Yet the stars are so large that, in spite of their gaseous state, they are exceedingly heavy, some of them weighing much more than our sun. Other stars, however, are composed of material so heavy that a cubic inch of it would weigh at least a ton, and a strong derrick would be needed to lift a piece the size of a grapefruit.

Magnitude and Color of Stars. By the *magnitude* of stars we mean their apparent brightness, which ranges from a magnitude of about 1 to a magnitude of 6. This scale of magnitudes is arranged so that a star of magnitude 1 is two and a half times as bright as a star of magnitude 2, which in turn is two and a half times as bright as a star of magnitude 3, and so on.

The different colors of the stars that can be seen by the naked eye are due to differences in temperature; a yellow star is hotter than a red star, and a blue star is hotter than a yellow star.

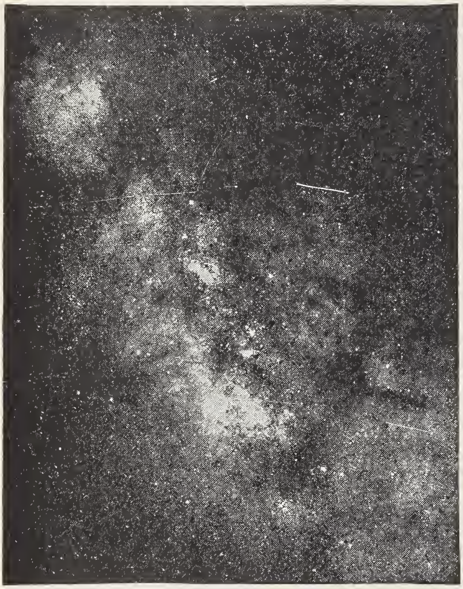


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Fig. 61–1. View toward the center of the Milky Way where the concentration of stars is greatest. The photograph shows the great cloud of dust in Sagittarius, just below the center of the picture.

Star Distances. The distances of the stars from the earth are indeed *astronomical*. Astronomers have therefore devised a unit, the *light-year*, in which to express them. Light travels at the rate of 186,000 miles per second, or 11,100,000 miles per minute. The distance from the sun to the earth is 93,000,000 miles, and from the sun to Pluto, the outermost planet in our solar system, 3,670,000,000 miles. It therefore takes light $8\frac{1}{2}$ minutes to travel from the sun to the earth, and 331 minutes to travel from the sun to Pluto. In other words, we could express these distances as $8\frac{1}{2}$ and 331 *light-minutes*. But this scale is too small to measure star distances. The distance from the earth to Alpha Centauri, the nearest star beyond the gap that separates our solar system from the rest of the universe, is 134,000,000 light-minutes. This distance is better expressed as $4\frac{1}{3}$ *light-years*, meaning that it takes the light of Alpha Centauri $4\frac{1}{3}$ years to reach the earth. The light from more distant stars may take 500 or even 2,000,000 light-years to reach us. Astronomical distances, then, are reckoned in light-years.

Demonstration 61—1. Comparison of the Astronomical Unit and Light-Year.

The sun-earth distance of 93,000,000 miles is often used as a unit to express distances within the solar system. This is the distance traveled in $8\frac{1}{2}$ minutes by light. Using a large roll of paper tape like that used in an adding machine, mark a starting point for the position of the sun. Taking a unit of 1 millimeter for the distance traveled by light in one minute, locate the position of the earth and the position of Pluto on the roll. (Using the distances given in the table in Chapter 59, calculate the proportional length needed on this scale.) Now calculate the number of minutes in 4.3 years and place a mark on the roll for the position of the nearest star. Explain your results in terms of distance.

HOW ARE STARS DISTRIBUTED IN SPACE?

Astronomically speaking, most of the stars we see are merely in the foreground of the picture of the universe. Beyond them is the great belt of pearly light known as the Milky Way, made up of millions of stars. And beyond the Milky Way astronomers have picked

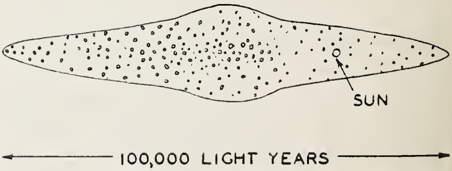
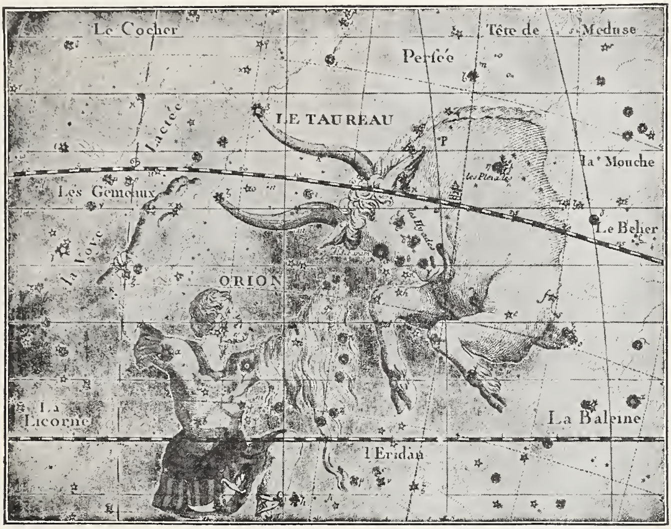


Fig. 61–2. The star system of the Milky Way. Note the position of the sun about midway between the center and the rim.

up light from swarms of stars more than 150,000 light-years away.

The Milky Way. On a clear starry night, particularly when there is no moonlight, you may have noticed a broad band of faint stars across the skies. This is the *Milky Way,* a name first used by the ancient Greeks. Examined with the field glasses, the luminous veil of the Milky Way shows a tremendous number of faint stars.



From Atlas Celeste de Flamsteed, *1776*

Fig. 61–3. Orion and Taurus.

Where there is apparently only a dim glow of light a small telescope can distinguish many more stars in the same field, and a photograph of such a field would show an almost unbelievable number of stars. The farther we go to the right and left of the Milky Way, the fewer is the number of visible stars. *The Milky Way therefore represents a high concentration of stars in a narrow zone.*

In clear regions the band of the Milky Way touches the horizon, and from observations below the equator we know that *this band encircles the earth.* Astronomers have learned through photography that in the Milky Way there are strangely luminous masses of gas and stars which are called *nebulae.* We shall discuss these nebulae later in this chapter.

The Milky Way can be compared to an enormous wheel of stars rotating in space. The sun is about midway between the hub and the rim, or about 30,000 light-years from the hub of the system. (See Fig. 56–2.)

The accumulation of millions of stars in our Milky Way system is called a *galaxy.* From measurements it appears that our galaxy has a diameter of about 100,000 light-years. Almost all the visible stars are located within this distance.

Constellations. Have you ever noticed that certain stars appear to form definite figures? About four thousand years ago imaginative Arab and Greek astronomers associated these patterns with real or fanciful creatures. Many of their names, such as Lion, Great Bear, Bull, Dragon, Scorpion, and Orion, have survived, and their classical names—Leo, Ursa Major, Taurus, Draco, Scorpius, and Orion—are still used for some of the star patterns, or *constellations*. The constellations divide the sky into regions. Ptolemy recognized 48 constellations; the sky is now divided into 90 constellations.

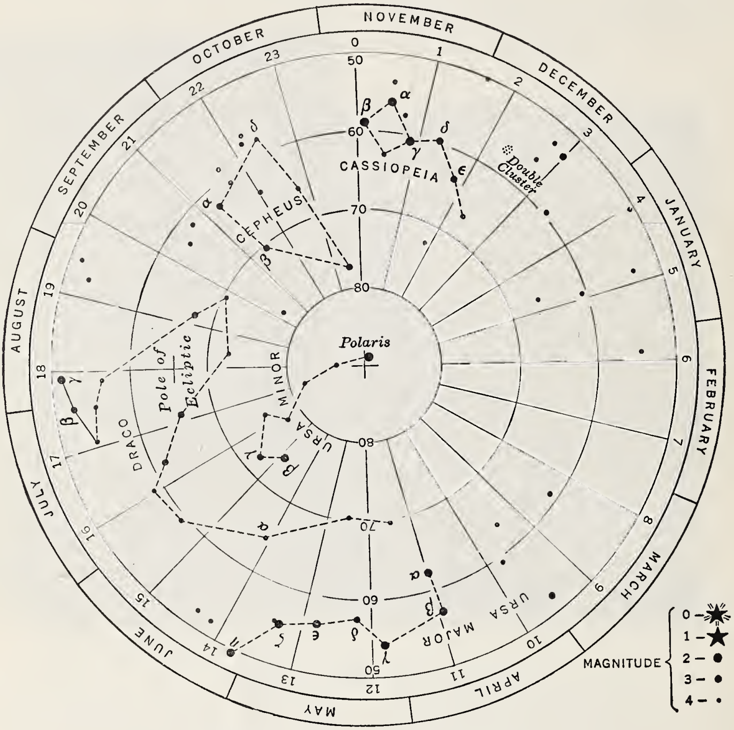


Fig. 61–4. The northern constellations.

The stars in each constellation are identified by Greek letters, and most of the brighter stars have names originating in the past. Usually the brightest star in a constellation is known by the first letter in the Greek alphabet, *alpha*; the next brightest by the second letter, *beta*, and so on through the Greek alphabet. Thus *Alpha Centauri* designates the brightest star in the constellation Centaurus. The outstanding exception to this method of labeling stars is in the constellation Ursa Major (the Great Bear or Big Dipper), where the letters are given in the order of sequence in the constellation instead of in the order of brightness.

Because of the rotation of the earth on its axis, all the constellations appear to rotate around *Polaris*. Polaris is almost exactly over the North Pole of the earth. It is therefore also called the *North Star* or *polestar*. If the earth's axis were extended indefinitely, it would appear to be directed straight at Polaris.

As the earth speeds along its course around the sun, different regions of the heavens are seen from the darkened side of our globe. Thus, some constellations are visible at one season and not at another. The constellation Orion (the Hunter), for instance, is easily recognizable in the winter sky but is not visible during the short summer nights. The constellation Hercules, on the other hand, is easily observed during the summer but not during the winter.

It is a simple matter to learn the names of the principal constellations and their brightest stars. There are many books and charts that will help you to determine the names and locations of stars. Furthermore, many amateur astronomers are grouped into societies that organize public observation nights and constellation classes.

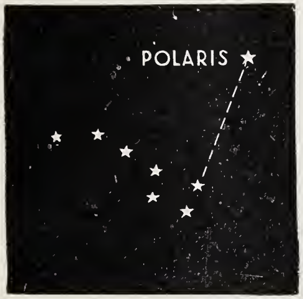


Fig. 61–5. Relative positions of the Big Dipper and Polaris about 8 P.M. on October 1.

Probably the best-known constellation is Ursa Major, the Great Bear. It is usually called the Big Dipper because the seven brightest stars in it are arranged in the form of a dipper. The two stars in the side of the Dipper farthest from the handle serve as pointers in locating Polaris. Once you have located Ursa Major, you will easily find other nearby constellations with the help of a star map.

It should be remembered that stars in the same constellation are not necessarily near one another, and that stars that appear to be rather close together may actually be enormous distances apart.

Gaseous Nebulae. Besides stars, our Milky Way has other remarkable objects called *gaseous nebulae.* Perhaps the best example, barely visible to the naked eye, lies in the constellation Orion. The middle "star" of Orion's sword appears to be slightly hazy. A photograph of this region shows that this hazy patch is actually a mass of gas made luminous by the presence of a group of stars and partly obscured by dark matter located between the gas mass and the earth. These nebulae, which are most frequent in the region of the Milky Way, are not seen easily by the eye or even by telescope; but photography has revealed a large number of them.

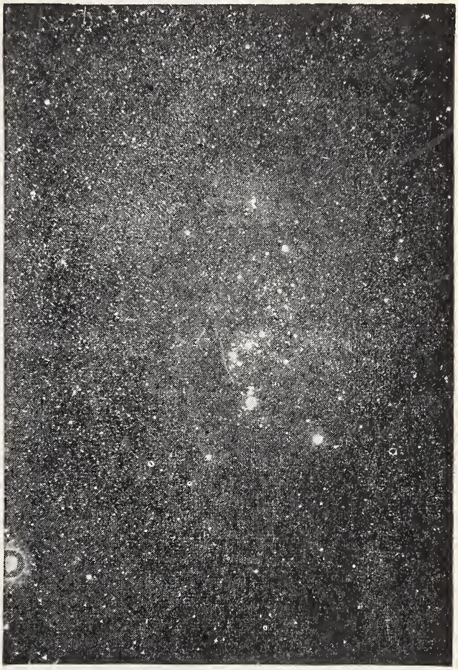


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Fig. 61–6. Constellation of Orion. This photograph covers almost one-twentieth of the whole sky. Sirius, the brightest star in the sky, appears near the lower left corner.

Dark Clouds of Matter. A perplexing element of our galaxy is cosmic dust, which has been revealed by the curious lessening in number or by the absence of stars in some parts of the skies. Astronomers now have proof that the stars are not really absent in these "empty" regions but that between the stars and the observer there are large clouds of dark matter that blot out the starlight. The best example of such an obscuring cloud of dust, clearly visible to the naked eye, is seen by observing the Milky Way from the region of Cygnus, through Aquila, and toward Sagittarius and Scorpius (see Fig. 61–1). It appears to be split in two in an irregular way. This big rift in the Milky Way is really an optical illusion due to the presence of a long cloud of matter nonluminous and opaque enough to cut off the light of millions of stars. It is easily visible in August and September.

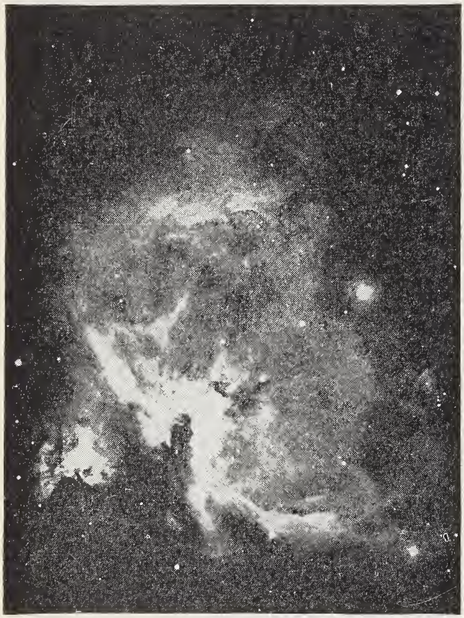

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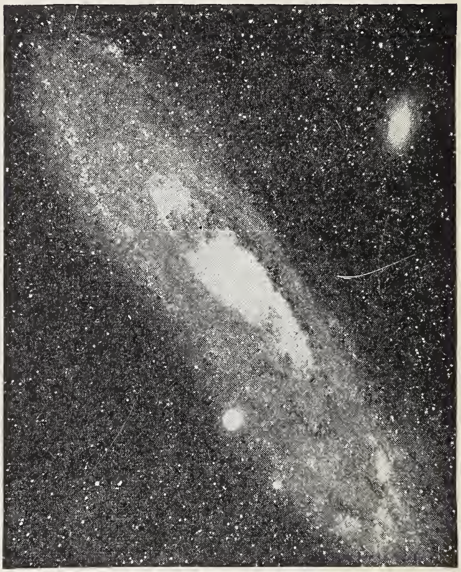
Fig. 61–7. The great nebula in Orion. It is near the middle of the three stars in line with Orion's sword.

Outside Galaxies. Observation of the region of Andromeda by the unaided eye shows a distinct spot of faint light. Field glasses reveal an oval area of light, which exhibits all its beauty only when observed with the telescope or the photographic plate. This is the great nebula in Andromeda. Unlike the Orion nebula, which is a part of our own galaxy, the nebula in Andromeda is one of a large number of galaxies outside our own.



Yerkes Observatory

Fig. 61–8. The great nebula of Andromeda. This nebula is made up of millions of suns and is about one million light-years away.

In recent years astronomical photography has revealed individual stars in this outside galaxy. The number of stars is similar to that of our own galaxy. In dimensions Andromeda's galaxy is about the same size as our own, but it must be at least 1,000,000 light-years away. In other words, the light that reaches us today left the stars in Andromeda's nebula a million years ago. Many other nebulae, all at great distances, have been found and studied. These outside galaxies are made up of millions of stars moving together as a whole and separated from one another by millions of light-years of empty space.

The Metagalaxy. The farthest of these galaxies is thought to be 200,000,000 light-years distant. How many other groups exist beyond the reach of our instruments no one, of course, can tell. Perhaps some of the more recent developments of electronics, together with our newer instruments, will reveal them. For the present, astronomers picture the whole known universe as a *metagalaxy* in which galaxies are to the metagalaxy as individual stars are to their own galaxy. Does it have an end? If so, what is beyond? How is it kept in motion? It is obvious that even astronomers cannot answer these questions with assurance—they can only make intelligent guesses. Actually they think of the universe as curving back on itself to form a closed space, and not as a vast depth of space stretching endlessly away in all directions.

But is space crowded? Is there danger of collisions between stars? Space—which includes all the stars and planets—is almost a vacuum, almost completely empty. To get a picture of the emptiness of space, imagine that three, and only three, wasps are present on the whole continent of Europe. In such a case Europe would be more crowded with wasps than space is with stars.

Until a century or so ago astronomers were interested only in the sun, the moon, the planets, and a few of the nearest stars. But this was because they were limited by their instruments. As their telescopes were improved and other instruments developed, they were able to see farther and farther into space. Indeed, the advance in astronomy has been similar to the advance in the knowledge of the surface of our own earth and of navigation. At first, navigation was limited to the inland seas—to the Mediterranean, for instance. Later, when Columbus suggested the possibility of traveling around the world, some people thought him insane. Today astronomers think of the universe as Columbus thought of the earth; they believe that if we could travel through space in the same direction, we would ultimately return to our starting position.

THINGS TO REMEMBER

Visible stars are suns, some larger and some smaller than our sun.

Planets are solid and reflect the light of the sun; stars are gaseous and incandescent.

Astronomical distances are measured in *light-years.*

The *Milky Way* is a band of stars that encircles the earth; these are the stars of our own galaxy.

The sky is divided into *constellations*, many of which are named for real or imaginary creatures.

Gaseous nebulae consist of gas made luminous by the radiation of nearby stars.

The numerous *outside galaxies* are millions of light-years from us.

All galaxies, including our own, are part of a *metagalaxy.*

QUESTIONS

A

1. Which of the answers to each of the following statements is correct?
   (*a*) The Milky Way is: (1) a mass of gas; (2) a cloud of dust; (3) an accumulation of stars.
   (*b*) A light-year is: (1) a unit of light; (2) a unit of time; (3) a unit of distance.

2. Why do astronomers use two different units for indicating planet distances and star distances?

3. What does the color of a star indicate?

4. What is a galaxy?

5. What property of a star is described by the term *magnitude?*

6. (*a*) What is a light-year?
   (*b*) Sirius is 8.6 light-years away. What does this mean?

B

7. Calculate the number of miles corresponding to a light-year.

8. Describe the picture the astronomers have formed of our galaxy.

9. Describe our galaxy and the relation of the sun to the galaxy.

10. State at least three differences between stars and planets.

11. What, briefly, is the picture presented by the term *metagalaxy?*

12. If the distance from the earth to the sun is represented by a line one inch long, how long a line would be needed to represent the distance to the nearest star (Alpha Centauri), which is 4.3 light-years away?

PROJECTS

1. *Charting Stars.* Some stars located around the polestar never seem to dip below the horizon. They are called *never-setting stars* and are visible every clear night throughout the year.

   The first thing to do is to locate the polestar. Remember that two stars of the Big Dipper are commonly called the pointers; they point to the place where the polestar is to be found. Having located the polestar, draw a chart by using the pointers and the polestar as a starting line. Place the polestar in the center of your map. Then locate the other stars on your chart by relationships between these stars. Gradually extend your chart to take in the principal stars visible in the north.

2. *To Study the Principal Constellations.* We know that some of the stars appear to be in groups known as constellations. A study of the constellations is an interesting project. Provide yourself with a star map or a star book, a flashlight whose light has been dimmed by covering the lens with dark red paper, a drawing pad, and pencils. Your star study can begin at the North Star and at the pointers in the Great Bear constellation. Gradually build up your knowledge of the constellations by searching the sky for these groups of stars. When you have made a complete observation of the sky, try to draw some star maps of your own. Indicate by dots, larger or smaller, the relative brightnesses of the stars. By means of dotted lines you can join together stars belonging to the same constellation.

Chapter 62

ENERGY FROM ATOMS

Heat Energy of the Sun and Stars. We have referred frequently to the high temperatures of the sun and the stars. The temperature of the surface of the sun is about 6000° C., and the temperature at its center is probably about 20,000,000° C. What causes these high temperatures? At first it was believed that the sun was a ball of fire caused by the ordinary processes of combustion. Nineteenth-century scientists showed by calculations, however, that if the sun were pure carbon supplied with enough oxygen for combustion, it would be burned up in a few thousand years, which was far less than the estimated age of the earth. Therefore ordinary combustion in the sun and the stars could not have taken place. Scientists realized that there must be some other immensely powerful source of energy. Henri Becquerel, a French scientist, provided the first clue to the explanation of stellar energy in 1896, when he showed that *sources of energy are hidden within the atom.*

Fig. 62–1A. Pierre Curie.

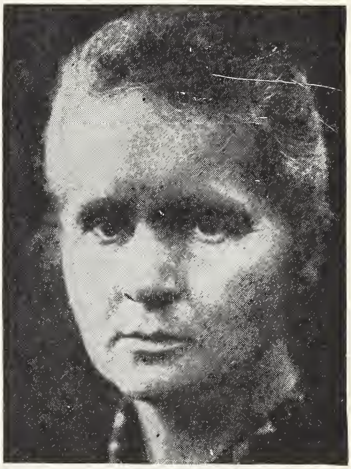


Fig. 62–1B. Marie Curie.

It was more than thirty years, however, before scientists could establish the connection between Becquerel's discovery and the sun's radiation. Then was developed the theory that in the sun hydrogen atoms are transformed into helium atoms, or, to be more exact, groups of four hydrogen atoms are converted into one helium atom. The weight of a helium atom (4.004) is a little less than the weight of four hydrogen atoms ($4 \times 1.008 = 4.032$). The difference between these two weights is important; it is the weight "lost" during the atomic conversion that *is transformed into heat and other radiations.*

This *conversion of matter into heat energy* is the source of the sun's heat. It is usually referred to as *atomic energy.* If this explanation is correct, it follows that the sun is slowly losing weight or, in other words, the sun's substance is slowly being destroyed. It can be shown that by this process the sun loses about five million tons of matter per second. This need not alarm us, for hydrogen is by far the most abundant element in the universe, and our sun will be able to supply this atomic heat energy for at least ten billion years.

Since all sources of power on earth are the result of the sun's radiation, it follows that the ultimate source of all our power is the energy released by the atomic reaction in the sun. This is true of coal, oil, water power, and even wind. Indeed, it is also true of the horse that works on the farm. He, too, runs on atomic energy because he eats grass which needs the sun's radiation in order to grow, and the sun's radiation comes from atomic energy.

RADIOACTIVITY

The release of energy by the sun raises an interesting question: Can man also release atomic energy? The sun's energy is released by *building up* a heavier element (helium) from a lighter element (hydrogen) at temperatures over 1,000,000° C. Is it possible for man to release atomic energy by the opposite operation, that is, by *breaking down* heavier atoms into lighter atoms at *ordinary* temperatures? To answer this question, let us return to the investigation of Henri Becquerel in 1896.

Becquerel and the Curies. One day Becquerel happened to place a piece of uranium ore on a photographic plate that was wrapped in black paper. Later he took a photograph with this plate and found that it was badly fogged. To determine the cause of the fogging, he placed other uranium minerals on covered photographic plates and left them in a dark room. Since the same fogging effect was present on all the plates, Becquerel was convinced that *these minerals give off invisible radiations.* They are, he said, *radioactive.*

Pierre Curie (a colleague of Becquerel) and his wife Marie became interested in this phenomenon. They examined pitchblende, which is the most common ore of uranium, and found that it was even more radioactive than a pure uranium compound. From pitchblende they isolated *radium,* which is more than a million times as active as uranium. For their work in radioactivity the Curies shared the Nobel prize in physics in 1903, and in 1911 Madame Curie was awarded the Nobel prize in chemistry.

Rays Emitted by Radium. At the beginning of the present century many of the leading scientists turned their attention to the study of radioactivity. It was obvious that the "Becquerel rays" came from the atoms of radioactive elements. What was the nature of these rays? And what kind of atomic structure will give off these rays?

Seeking the answers to these questions, Lord Rutherford, a British scientist, performed the following experiment. He placed a few grains of radium in a narrow lead tube, and near the opening of the tube he put a screen of zinc sulfide, which glows when bombarded with radioactive rays. A single small circular glowing patch appeared on the screen. When he placed a strong magnet or an electric field near the beam, the beam at once broke up to form three patches on the screen.

The arrangement of these patches is shown in Fig. 62–2. It was apparent that three different kinds of rays were emitted by radium. Rutherford called them *alpha, beta,* and *gamma* rays.

Alpha Rays. The direction in which the alpha rays were deflected proved that these rays are *positively* charged particles. It was shown later that they are made up of the *cores,* or *nuclei, of helium atoms,* that is, of helium atoms from which the outer electrons have been stripped off. Alpha rays travel at high speeds, about one-tenth as fast as light.

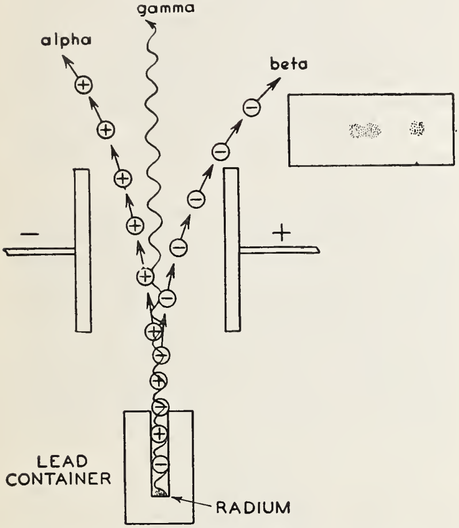


Fig. 62–2. Rays from radium. The circular glowing patches on the zinc sulfide screen are shown on the right.

Beta Rays. The deflection of the beta rays showed that beta rays are made up of negatively charged particles that travel almost as fast as light. *These negative beta particles are electrons.*

Gamma Rays. The gamma rays were not deflected, which shows that they are not charged particles. Actually *they are electromagnetic waves,* slightly shorter than X rays, that travel with the velocity of light.

Radon. In addition to alpha, beta, and gamma rays, *some heat was generated* and a gas was formed that made the surrounding air a conductor of electricity. This gas was originally called *radium emanation;* the term was later contracted to *radon.*

Radium has an atomic weight of 226, radon an atomic weight of 222, and an alpha particle an atomic weight of 4. *It therefore looked as though an atom of radium changed to an atom of radon by emitting an alpha particle,* or,

radium atom → radon atom + alpha particle

This radioactive change is taking place continuously. It has been determined that half of a radium mass changes to radon every 1690 years. That is, in 1690 years one half of the radium becomes radon; in the next 1690 years one half of the remainder changes, and so on indefinitely. Thus a given sample of radium has a life that is infinitely long and, for this reason, the life expectancy of radium, or of any other radioactive element, is usually expressed in terms of its *half-life period.*

Radioactive Changes. All uranium ores contain radium as well as other radioactive substances. Alpha, beta, and gamma radiations and heat waves are constantly being given off. The radiations come from the interior of the atom, and as a result the atom changes from one kind to another. When an alpha particle is emitted, the atomic weight of the atom is reduced by 4; when a beta particle is emitted, the atomic weight is not seriously affected because the weight of an electron is negligible. But *whether an alpha or a beta particle is shot off, a new radioactive element is formed, and the process continues until the element lead is formed.* The end product of all natural radioactive transformations is lead. This lead is not radioactive and therefore does not disintegrate further.

Between uranium and lead no fewer than fourteen nuclear disruptions occur, and each change is accompanied by the release of energy in the form of heat and gamma rays. The half-lives of these elements vary enormously. Sometimes the change takes place in seconds or minutes, sometimes in tens of thousands of years.

The energy released by radioactive changes is far greater than that released by such chemical reactions as the burning of gasoline or the explosion of dynamite. The *rate* at which energy is released is obviously slow. Scientists have tried to increase the speed of these radioactive changes, but thus far they have not succeeded. Heating a radioactive substance until it is incandescent or immersing it in liquid air does not affect the speed at which it breaks up.

Nevertheless, scientists realized that radioactive atoms—and probably other atoms—contain enormous amounts of stored-up energy that might conceivably be used in the service of mankind. While they were still concerned with the problem of releasing atomic energy, they found some uses for radioactive elements in medicine, industry, and geology.

Uses of Radium and Radon. The gamma radiations from radium and radon are effective in the treatment of cancer and certain skin diseases, since these rays destroy cancer cells more easily than they attack normal tissue. Radon gas is collected from a radium salt and sealed in small tubes to be used for such purposes.

Radium has a commercial value. When alpha particles strike a substance like zinc sulfide, they produce flashes of light. Zinc sulfide paint containing a trace of radium salt is therefore used in making luminous watch dials.

Radioactive rocks have also been used to determine the age of the earth. The method of doing this is discussed in Chapter 8.

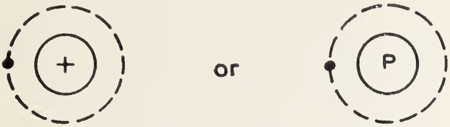
THE APPROACH TO ATOMIC ENERGY

In the early years of this century considerable progress was made toward solving the mysteries of atomic structure, and probably the contributions of Rutherford were the most outstanding. The emission of alpha, beta, and gamma radiations by a radioactive substance convinced Rutherford that an atom consists of two parts—a tiny nucleus, where the radioactive changes take place, and some outer electrons. The outer electrons are easily disturbed by friction and therefore give rise to the electric charges discussed in Chapter 35. They also take part in chemical reactions.

Rutherford's next step was an attack on the nucleus itself. In 1919 he bombarded nitrogen atoms with alpha particles emitted by radium and obtained the nuclei of hydrogen atoms. He then bombarded other atoms, and *out of every bombarded atom he obtained the nucleus of a hydrogen atom.* He therefore regarded the hydrogen nucleus as a building block in atomic structure. He called it a *proton,* a Greek term meaning "first."

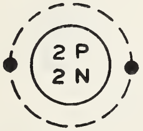
The most important conclusion that Rutherford drew from his experiments was that *the nuclei of ordinary atoms are complex structures and that protons are part of the nuclear structure.* For his important contributions to the theory of atomic structure Rutherford was awarded the Nobel prize in chemistry in 1908.

Structure of the Hydrogen Atom. The simplest atom is, of course, the hydrogen atom. It consists of a nucleus with a single proton and of a single electron outside the nucleus. The whole atom is therefore neutral; but if the electron is lost, a positively charged particle, or proton, remains. The hydrogen atom can therefore be represented diagrammatically as

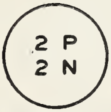


Helium Atom. The next advance in the release of atomic energy was made by Chadwick, one of Rutherford's research students. In 1932 Chadwick discovered *neutral* particles, which he called *neutrons*. This discovery was an important link in the chain that led to the release of atomic energy, and in 1935 Chadwick was awarded the Nobel prize in physics.

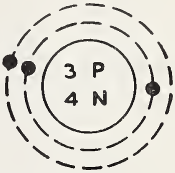
Let us now examine an atom of fairly simple structure such as helium. Helium has an atomic weight of 4; therefore the sum of the protons and neutrons in its nucleus must also equal 4. Moreover, the helium atom has 2 electrons outside the nucleus; to make the atom neutral the nucleus must therefore contain 2 protons. It follows that it must also contain 2 neutrons. A diagram of the helium atom is, therefore,



The diagram of an alpha particle or a helium nucleus is



Lithium Atom. Another atom whose structure we must examine is that of lithium. Lithium is a metal. Its atomic weight is 7. Therefore the total number of protons and neutrons in the nucleus of its atom must also be 7. As this atom has 3 electrons outside the nucleus, it must have 3 protons in the nucleus to form a neutral atom. From this it follows that the nucleus must contain 4 neutrons as well as 3 protons. A diagram of the lithium atom is



We must, of course, bear in mind that atoms are mostly empty space. If the nucleus of an atom could be enlarged to the size of a baseball, the nearest electrons would be 2,000 feet away.

Fission of Lithium Atoms. In 1932 two colleagues of Chadwick and Rutherford, working in the same laboratory, continued the investigation of atomic structure. They directed a stream of protons against a film of lithium, and found that from the impact alpha particles were shot off at high speed. This simple transformation is shown in Fig. 62–3.

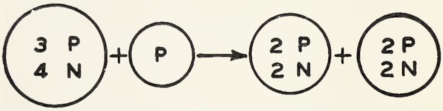
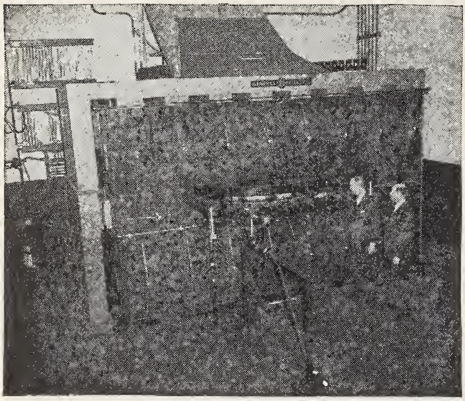


Fig. 62–3. Fission of a lithium atom.

In this diagram we have omitted the outer electrons, since we are concerned only with nuclei. The diagram shows that a proton has split a lithium nucleus into two equal parts. Moreover, sufficient energy was liberated to cause the fragments to fly apart at high speed. This experiment is important because *it was the first case of nuclear fission.*

Notice that nuclear fission is quite different from radioactivity. In fission, two equal, or nearly equal, fragments are obtained; whereas



Courtesy General Electric Co.

Fig. 62–4. A large betatron used in atomic research in which electrons are accelerated to very high speeds. Notice the large electromagnet, an essential part of the apparatus, in the center of the picture.

in radioactivity, alpha, beta, and gamma particles are given off. Moreover, man has no control over radioactivity, but he can cause fission by bombarding a nucleus.

Bombardment of Nuclei. Both protons and alpha particles were used as projectiles to bombard the nucleus. Since both these particles are positively charged, and since the nucleus of an atom is also positively charged, there was a repulsive force between projectile and nucleus. As a result the projectiles had to be hurled at enormous speeds before they could overcome the force of repulsion and penetrate the nucleus. Scientists designed machines, such as the Van de Graaff generator, to hurl the particles at higher and higher speeds.

But while these machines did much to increase our knowledge of atomic structure, they did not provide an efficient method of *releasing* atomic energy. In fact, more total energy was used in hurling the projectiles than was released by the impacts between nucleus and projectile. We must remember that the nucleus is an exceedingly small target and that the protons and neutrons occupy only a small fraction of the volume of the nucleus, which is almost empty space.

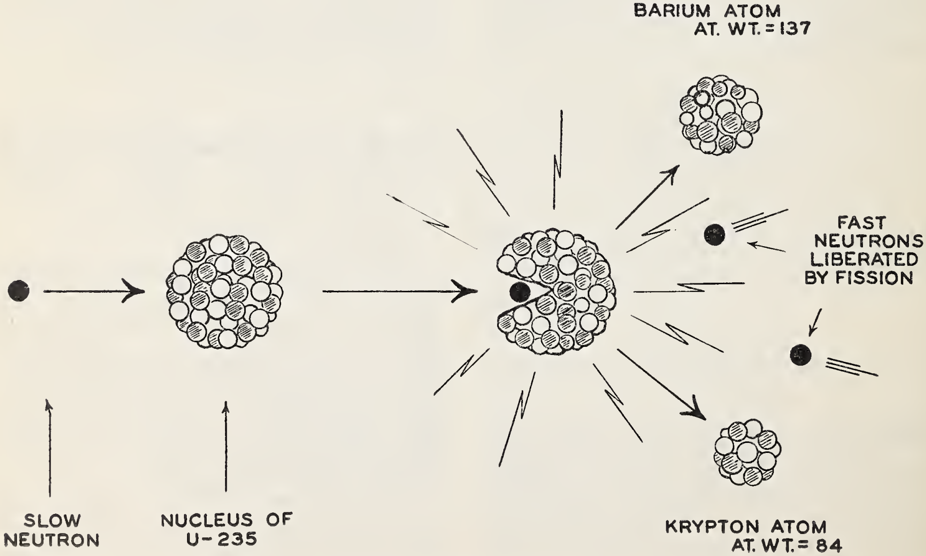


Fig. 62–5. Fission of uranium.

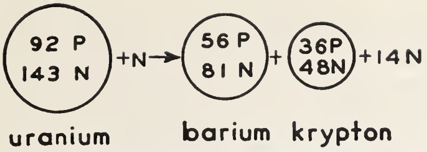


Fig. 62–6. Neutrons and protons involved in uranium fission. Note particularly the role of the neutrons in the reaction.

In 1933 Enrico Fermi, then working at the University of Rome, began using *neutrons* as projectiles. This proved to be the key to the secret of atomic energy. Neutrons have no charge, and are therefore not repelled by the positive nuclei of atoms; consequently they easily penetrate the nuclei. Moreover, slow neutrons are effective in breaking up nuclei. The machines used for developing high-speed projectiles were no longer an essential part of the fission process; and for the first time the release of atomic energy as a practical process became a possibility. Fermi was awarded the Nobel prize in physics in 1937 for his work on neutrons in the fission process.

Atomic Energy. In January, 1939, two German chemists, Strassmann and Hahn, announced that they had used slow neutrons to break up the uranium nucleus and that one of the products was barium. The nucleus of the uranium atom contains 92 protons; the barium nucleus, 56 protons. The difference between 92 and 56 is 36. Since the element that has 36 protons in its nucleus is krypton, it appeared that krypton might be the other product of the fission process.

Let us look at the neutrons involved in

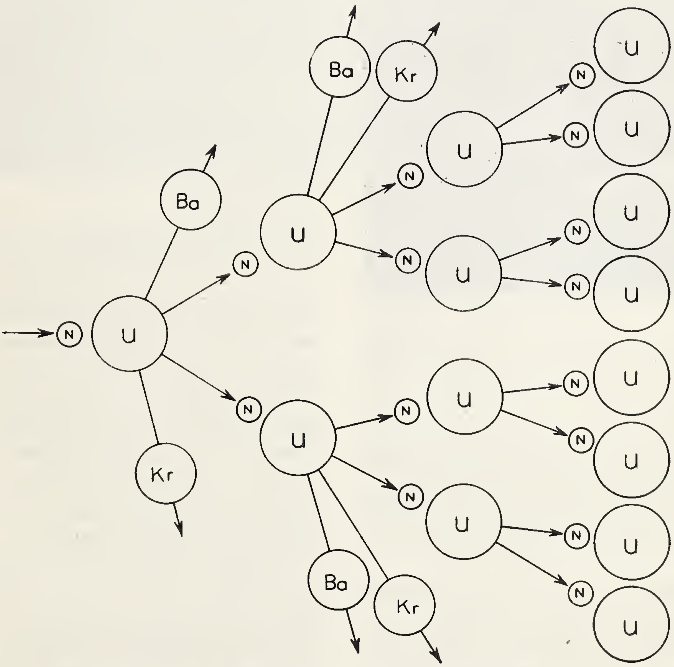
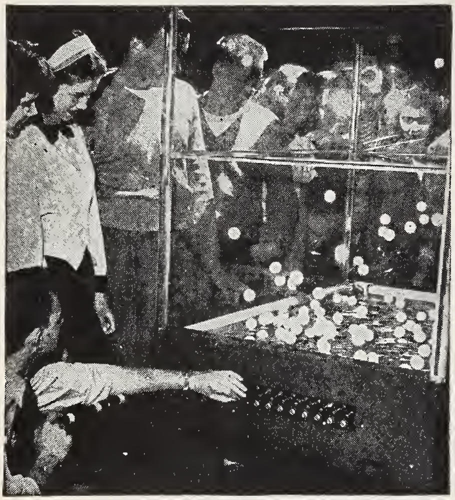


Fig. 62–7. A chain reaction. The neutron on the left causes the fission of a uranium atom, thereby releasing two neutrons. Each of these neutrons causes the fission of another uranium atom, and the released neutrons cause the fission of more uranium atoms.

this transformation. Uranium has 143 neutrons, barium has 81, and krypton 48. The total number of neutrons in barium and krypton is 129, which is 14 less than the number of neutrons in uranium.

In other words, *a neutron was needed to start the fission process, but a number of additional neutrons were released during the process.* Could these released neutrons be used to continue the fission process, that is, to start a chain reaction? In 1939 this was the international scientific question. We now know that, during World War II, American scientists found the answer to this question. By controlling the process they were able to release atomic energy on a large scale.



Courtesy Monsanto Chemical Co.

Fig. 62–8. High-school students watch a demonstration of an atomic chain reaction in which neutrons are represented by Ping-pong balls.

A Chain Reaction. We have already seen that the capture of a single neutron by a nucleus of uranium (of atomic weight 235) causes the uranium nucleus to split into two main fragments, barium and krypton, which fly apart with tremendous energy. If no neutrons were released, the reaction would stop after the disintegration of a single atom. Actually, however, neutrons are released in the fission process. These neutrons explode other nuclei, which, in turn, liberate more neutrons. In this way a self-sustaining chain reaction is started. Thus in the fission process a small amount of mass is converted into energy which causes the new nuclei to move at great speeds, and the resulting temperature may approach that of the interior of the sun.

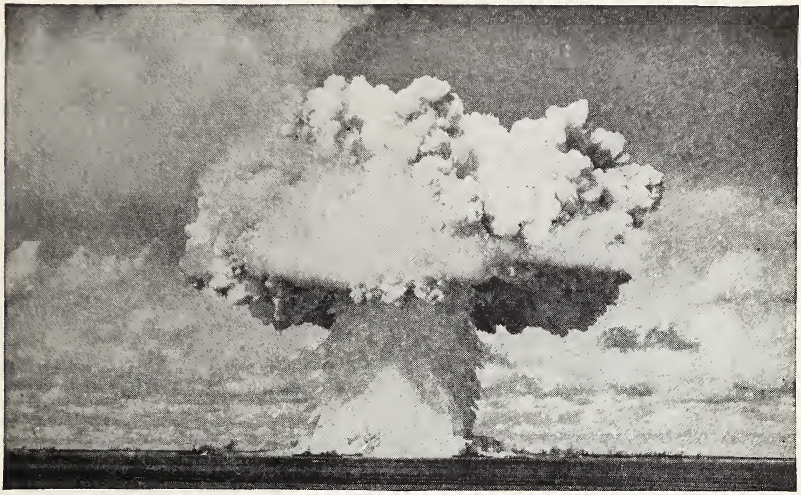
The Atomic Bomb. The chain reaction can either be controlled so that it proceeds slowly or it can be allowed to get out of control. In the latter case disintegration takes place almost instantaneously with devastating effect, as in an atomic bomb. The "explosion" of the bomb is accompanied by enormously high temperatures—far higher than the temperature of the surface of the sun—and by the release of powerful radiations, such as neutrons, protons, electrons, and gamma rays—which are harmful to living tissues. The single atomic bomb that exploded over Hiroshima in Japan during World War II killed more than 75,000 people.

The Uranium Reactor. If atomic energy is to be used for industrial purposes, the chain reaction must be controlled. This is done in the uranium reactor, which consists of many small rods of uranium embedded in huge graphite bricks. The graphite slows down to a speed of about one mile a second neutrons that are ejected at speeds of thousands of miles a second. The reactor is housed in a massive structure with concrete and steel walls about six feet thick that form a protective shield against the radiations emitted.

Uranium consists of two different types of atoms: one of atomic weight 235, called U-235; the other of atomic weight 238, called U-238. The heavier type is more than a hundred times as plentiful as the lighter type, but it is not fissionable; only the lighter, rarer type is fissionable.

In the reactor U-235 captures a neutron and fission takes place. A great deal of heat is liberated, which heats up the reactor. The fast-moving neutrons that are ejected are slowed down by the graphite, and some of them are captured by U-238 to form a synthetic, or man-made, element called *plutonium.* Plutonium is fissionable and is used as a source of atomic energy. In other words, the importance of the reactor is that, though it destroys the rare and fissionable U-235, it also converts the more plentiful nonfissionable U-238 into fissionable plutonium.

The uranium reactor and the sun are similar in that nuclear changes take place in both. There are two important differences between them, however. In the reactor or pile, nuclear *fission* takes place. *This change occurs at ordinary temperatures,* because only neutron bombardment is needed to split U-235. In the sun, nuclear *fusion* takes place—that is, hydrogen atoms are fused into helium atoms. *This change occurs only at very high temperatures,* because tremendous heat is necessary to convert a light element into a heavier one. Some scientists now believe that it is possible for man to build helium atoms from hydrogen atoms, and thus produce a reaction which will release several times as much energy as the explosion of a plutonium bomb.



Courtesy Joint Army-Navy Task Force

Fig. 62–9. An experimental underwater blast in Bikini Lagoon, July, 1946. A single atomic bomb sent up a column of water weighing almost 10 million tons to a height of 4,000 feet. The photograph was taken from the island of Bikini. Three battleships were sunk in the explosion.

THINGS TO REMEMBER

The *sun's heat* is probably caused by the conversion of some mass to energy as hydrogen atoms are being converted into helium.

A *radioactive element* undergoes nuclear changes by giving off alpha, beta, and gamma radiations.

Alpha particles are made up of helium nuclei.

Beta particles are streams of electrons.

Gamma rays are electromagnetic waves that are slightly shorter than X rays.

Lead is the end product of all natural radioactive changes.

Protons and *neutrons* make up the nuclei of atoms.

In *nuclear fission* the nucleus is broken into two nearly equal parts, and intense radiations are given off.

In the *reactor* U-235 undergoes fission, and U-238 is changed to plutonium.

QUESTIONS

A

1. What scientific fact or event do you associate with the following: (*a*) Becquerel; (*b*) Curie; (*c*) Chadwick; (*d*) Fermi?

2. Why is uranium called a radioactive element?

3. Determine which of the following statements are true and which are false. Then correctly reword the false ones.

- (*a*) Beta rays are negatively charged.
- (*b*) Becquerel discovered radium.
- (*c*) Helium is the most abundant element in the universe.
- (*d*) Uranium ores are radioactive.
- (*e*) The nucleus of a hydrogen atom contains one proton and one neutron.
- (*f*) The fission of a uranium atom yields barium and krypton.

4. What is: (*a*) a proton; (*b*) an electron; (*c*) a neutron?

B

5. How do you account for the heat of the sun?

6. Describe the rays that may be given off by a radioactive substance.

7. What are the differences between radioactivity and atomic fission?

8. What happens when alpha particles or protons bombard lithium atoms?

9. What is meant by a chain reaction? Give an example.

10. What is a uranium reactor? What happens in the reactor?

11. What happens when a radioactive element like radium changes to radon?

PROJECT

Experimenting with a Radioactive Substance. Place a Welsbach gas mantle on a covered photographic plate in a dark room. After a week or so develop the plate, which shows an impression of the mantle where it has been fogged. Thorium is used in the manufacture of Welsbach gas mantles. It is radioactive and emits enough rays to fog the plate. This project is a modification of the Becquerel experiment.

Chapter 63

CHEMICAL AND NUCLEAR ENERGY

The discussion of atomic structure and nuclear energy brings to mind some questions unanswered in earlier chapters. Why are the sun and stars hot and the planets cold? How is coal able to store the sun's energy of past ages? Is nuclear energy essentially destructive? Can it be beneficial as well as harmful?

Why Is the Sun Hot and the Earth Cold? If we accept the tidal theory, the explanation is fairly simple. The heat of the sun is caused by nuclear reactions which take place only at exceedingly high temperatures. It is reasonable to suppose that, when the earth broke away from the sun, nuclear reactions were taking place within the earth's mass. Owing to its small size, the earth cooled relatively rapidly in space and eventually reached a temperature at which nuclear reactions ceased.

According to the dust-cloud theory, stars are born from cosmic dust. As the dust cloud contracts, the pressure inside it increases and its temperature rises enormously. Eventually it becomes white-hot, and the internal temperatures, caused by contraction, are high enough to start nuclear changes. This is one theory of the source of heat in the sun.

The planets, on the other hand, were formed by the condensing of much smaller clouds of dust. When they were first formed, they too were hot—probably hot enough to be molten. Since they are relatively small, the heat of contraction was not nearly so great as that generated in the sun; and the resulting temperature was not high enough to start nuclear reactions. That is why the planets do not radiate their own heat as the stars do. Instead, they gradually cooled until their only source of light and heat was the sun.

Difference Between Chemical Energy, as in Combustion, and Nuclear Energy. Let us see what happens to the atoms of carbon and hydrogen when sunlight falls upon them—that is, during photosynthesis. We will consider only the simpler atom, hydrogen. The hydrogen atom has a single proton as a nucleus and a single electron that whirls about this nucleus at high speed. If the hydrogen atom picks up energy (from the sun, for example), the electron is raised to a higher level or orbit, as is shown in Fig. 63–1. The electron continues to whirl in its new orbit until it releases the energy it has gained. Then the electron will fall back to its original level. In this way an atom can *store* energy, and that is why the sun's energy can be trapped and stored indefinitely in such atoms as hydrogen, carbon, and oxygen when they form carbohydrates.

During the process of combustion the electrons fall back to lower levels and release the energy that kept them at the higher level. This energy is the *heat of combustion*. It is released solar energy, and it is the source of all the power derived from coal and petroleum.

The difference between chemical and nuclear changes is now apparent. Chemical changes affect only the electrons in the orbits of an atom, never the nucleus; whereas nuclear changes affect the nucleus as well as the electrons. It is therefore more accurate to speak of *nuclear energy* than of atomic energy.

BENEFICIAL USES OF NUCLEAR ENERGY

Radioactive Elements. In the pile, or *reactor* as it is now called, the uranium "fuel" produces a large number of fission products besides plutonium. These products, which consist of many elements, absorb some of the neutrons present in the reactor and become radioactive; that is, they give off alpha and beta particles and gamma rays.

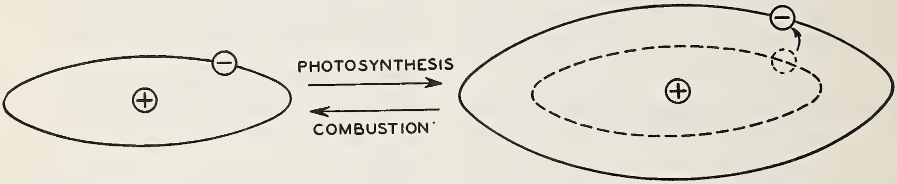


Fig. 63–1. In photosynthesis, energy is absorbed and electrons jump to a higher level; in combustion, energy is evolved and electrons fall to a lower level.

Radioactive elements behave like ordinary elements chemically. They can be detected, even in minute quantities, by a *Geiger counter*, which clicks loudly when it approaches them. Radioactive elements can therefore be used as *tracers*, or *tagged atoms* as they are often called.

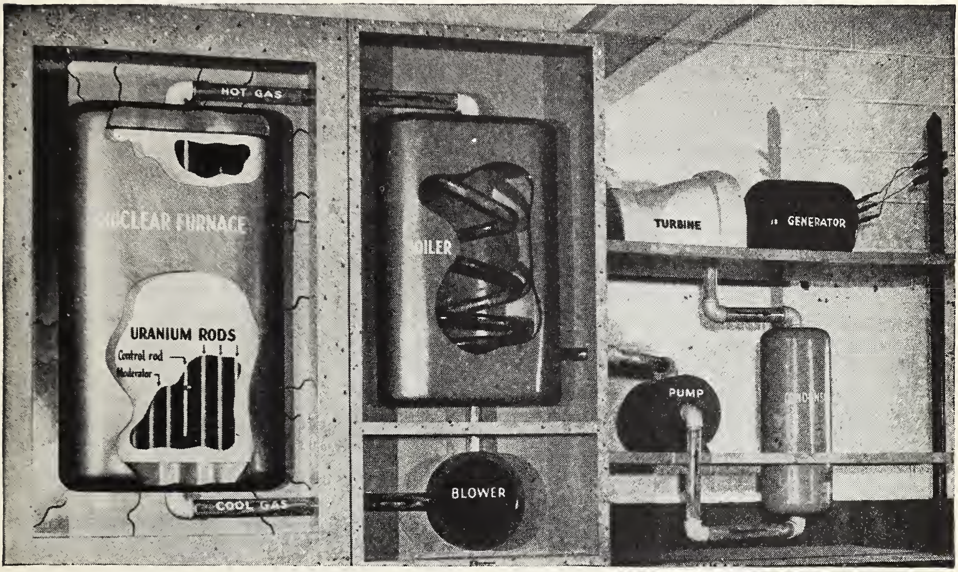
One such tracer is radioactive carbon, now used in the study of photosynthesis. If radioactive carbon is burned in oxygen to form carbon dioxide, the carbon will remain radioactive. When it is absorbed by a green plant, it can be traced to any part of the growing plant. With the aid of radioactive carbon scientists hope to discover the sequence of steps by which sugar, starch, and cellulose are made from carbon dioxide and water. With this knowledge they could manufacture food and even clothing from water and limestone.

Heat and Power from Nuclear Energy. When U-235 is split into two parts, a great deal of heat energy is released. In the pile, or reactor, the chain reaction takes place at a controlled rate, and the heat is available for doing work. One pound of U-235 consumed in this way will give as much heat as the combustion of 1,500 tons of coal.

When nuclear energy was first released by man, it was thought that new kinds of heat engines independent of chemical fuels, would shortly be developed. But many engineering problems must be solved before nuclear energy can be efficiently converted into electric power.

One problem involves temperature. Much higher temperatures are needed for generating power than for producing bombs. A power-plant reactor must therefore be able to withstand intense heat. Engineers have not yet been able to design a reactor that will operate at high temperatures. The common construction materials—steel and the nonferrous metals—absorb neutrons so fast that they would stop the chain reaction. Materials that do not absorb neutrons, on the other hand, lack strength, and they corrode at high temperatures. One of the requirements for a power-plant reactor, therefore, is a strong alloy that does not absorb neutrons at high temperatures. Experimental atomic power stations have been built, but the heat is generated at too low a temperature to make industrial production profitable. Also, the reactors are heated from the fission of U-235, which is expensive and rare.

Another engineering problem is the matter of *shielding.* Neutrons and other radiations are harmful to all living things, so massive shields of concrete at least six feet thick must be built around a reactor. As yet, engineers have found it impossible to build a safe engine that weighs less than 20 tons. The reactors developed thus far may eventually be used to run ships and submarines, but not automobiles or airplanes.



Courtesy Brookhaven National Laboratory

Fig. 63–2. An atomic furnace. When uranium atoms split, intense heat is given off, causing the uranium rods to become red-hot. A gas is pumped over the rods and the hot gas is led through coils to a boiler where it changes water to steam.

A Nuclear Power Plant. The experimental reactors used for generating power are similar to the one shown in Fig. 63–2. The heat of the reactor heats up a molten metal and vaporizes it. This vapor circulates around and flows into a heat exchanger, where it gives up its heat to the water, converting it into steam. The condensed vapor then returns to the reactor and is reheated. The steam, in the meantime, drives a turbine that rotates a generator to produce electricity. In this way nuclear energy produces electrical power.

Deposits of Uranium. Uranium is almost as abundant as lead in the earth's crust, but usually it is found in low-grade ores unprofitable to work. Only two mines are known that produce large amounts of high-grade ore. One is in northwestern Canada, at Great Bear Lake within the Arctic Circle; the other is in the Belgian Congo, in southern Africa. A third but smaller deposit is in Czechoslovakia. The Canadian deposit is by far the richest in the world. The ore is pitchblende, which contains both uranium and radium. During the winter the ore is concentrated and stored, and during the summer it is shipped to a refinery in Ontario, three thousand miles away. Relatively little uranium is found in the United States, although some is mined as carnotite in Colorado and Utah. If economical methods are developed for treating low-grade ores, or if large new deposits of uranium are discovered, there will be enough raw material to supply the world with power for many centuries.

In Retrospect. The large-scale use of atomic power belongs to the future. Man has discovered a source that offers either untold benefits or almost irreparable destruction. We saw that early man rubbed two dry sticks together to start a fire. It took him many centuries to learn to convert heat energy from fire into mechanical motion. Not until the end of the 17th century was the steam engine invented. It took two more centuries to learn to use directly the energy of burning fuel for the internal-combustion engine. Power depended on limited supplies of coal and oil.

It is significant that it is only a little more than half a century since Becquerel and the Curies opened the vast field of radioactivity, and yet scientists have already learned the secrets of the atom and revealed almost unlimited sources of energy. This new fuel of the 20th century will serve man with sources of energy hitherto used exclusively by the sun and the stars.

Finally, remember that the nuclear "fires" of atomic energy are neither new nor uncommon; they have supplied the light and heat of the stars since the beginning of time. Ordinary fires of coal and oil, on the other hand, are relatively rare. Coal and oil are formed from living matter—from plants and animals; they are compounds of carbon. And perhaps the only place in the universe where these compounds occur is on a comparatively tiny planet called the Earth.

THINGS TO REMEMBER

Chemical changes affect *electrons outside the nucleus* of the atom; nuclear changes affect the *protons and neutrons within the nucleus* of the atom.

Radioactive elements are formed in a nuclear reactor and emit alpha and beta particles.

Radioactive elements can be used as *tracers* in chemical, physical, and biological changes.

A *reactor* cannot successfully be used as a source of heat until alloys have been discovered that do not absorb neutrons.

The *richest uranium deposits* are found in the Belgian Congo (Africa), northwest Canada, and Czechoslovakia.

QUESTIONS

A

1. Explain what happens to the electron in a hydrogen atom during: (*a*) photosynthesis; (*b*) combustion.
2. What is a tagged atom? How is it formed?
3. Why is thick concrete shielding necessary around a uranium pile?
4. Name the sources from which the United States Government gets its uranium.

B

5. State a probable explanation of the source of heat in the sun.
6. Explain how radioactive carbon could be used in the study of photosynthesis.
7. Explain some of the problems to be solved before nuclear power can be used in airplanes.

REVIEW QUESTIONS ON UNIT 12

A

1. Describe briefly the observation made by Galileo on Jupiter and state the conclusion he made from this observation.
2. What is the origin of the name of the planet Pluto?
3. Name the planet that is: (*a*) nearest the sun; (*b*) farthest from the sun; (*c*) nearest the earth.

4. What are the distinctive features of Mars and Saturn when seen through a powerful telescope?
5. Explain the chief differences between a comet and a meteor.
6. Express one light-year in light-minutes.
7. Express the distance between the earth and Pluto in light-years.
8. Name and describe a constellation.
9. State the importance of Madame Curie's discovery.
10. Name: (*a*) the atom with two fundamental particles; (*b*) the nucleus with one fundamental particle.
11. What is the essential difference between a chemical reaction and a nuclear reaction?

B

12. Compare the ideas of Aristotle and Copernicus regarding the sun-earth relationship.
13. (*a*) What are sunspots?
    (*b*) How are they caused?
    (*c*) State some of their effects on the earth.
14. Explain the similarity between the tidal theory of the origin of the planets and the formation of tides.
15. How can you prove that the earth travels around the sun at a speed of about 18.5 miles per second?
16. Explain why the earth moves in a curved path.
17. "The moon has two kinds of motion." Explain what this statement means.
18. What causes: (*a*) a high tide; (*b*) a low tide?
19. Write what you know of the Milky Way.
20. Discuss briefly the three fundamental particles in an atom.
21. Draw a diagram of an atom of lithium and explain what it means.
22. Explain what happens in the fission of a uranium atom.

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GENERAL REVIEW QUESTIONS

A

1. Write briefly on the following scientists: (*a*) Newton; (*b*) Lavoisier; (*c*) Rutherford.

2. In which country did the following scientists live: (*a*) Edison; (*b*) Watt; (*c*) Lavoisier?

3. Write briefly on the following terms: (*a*) molecule; (*b*) element; (*c*) planet; (*d*) nucleus.

4. With what branches of science do you associate the following names: (*a*) Newton; (*b*) Faraday?

5. Give the significance of the following inventions: (*a*) the telescope; (*b*) the carbon-filament lamp; (*c*) the steam engine; (*d*) the thermometer; (*e*) the internal-combustion engine; (*f*) the atomic bomb.

6. For what purposes are the following instruments used: (*a*) spectroscope; (*b*) telescope; (*c*) barometer; (*d*) wet- and-dry-bulb thermometer?

7. For what purposes are the following devices used: (*a*) carburetor; (*b*) spark plug; (*c*) armature; (*d*) generator; (*e*) fractionating tower?

8. Compare and contrast the following terms: (*a*) heat and temperature; (*b*) conduction and convection; (*c*) power and work; (*d*) slow combustion and rapid combustion; (*e*) igneous and sedimentary; (*f*) star and planet; (*g*) jet and rocket.

B

9. Briefly describe an experiment in which:
(*a*) light is broken up into its component colors;
(*b*) an electric current is produced in a coil by a magnet;
(*c*) oxygen is shown to be essential for combustion.

10. Describe the construction of: (*a*) a barometer; (*b*) a generator.

11. Describe some of the important devices used with a modern telescope.

12. Write on the following: (*a*) galaxy; (*b*) diatoms; (*c*) fossils.

13. Compare the use of coal and food as fuels in engines.

14. Trace the steps by which vegetation is converted into coal.

15. (*a*) Name the two essential parts of a solution.
(*b*) How could you show that sap is a solution?

16. Write briefly on the Appalachians, including in your description information on the *age*, *kind*, and *erosion* of the rocks.

17. How do you account for the heat energy of the sun?

18. Compare and contrast combustion energy and atomic energy.

19. The position of New York is, roughly, lat. 40° N. and long. 75° W.
(*a*) Where is latitude measured from?
(*b*) What does "lat. 40° N." mean?
(*c*) Calculate the distance of New York from the equator, given the circumference of the earth as 25,000 miles.
(*d*) Where is longitude measured from?
(*e*) If it is 11 A.M. in New York, what is the time in London? Explain how you arrive at your answer.

Glossary

Absolute zero. The lowest possible temperature, $-273°$ C. or $-459°$ F.

Acoustics. Sound-absorbing and sound-reflecting properties of an auditorium.

Afterdamp. Gas formed after an explosion in a coal mine.

Air. A mixture of gases, mainly nitrogen and oxygen, that surrounds the earth.

Air mass. A mass of cold dry air from the polar regions or of warm moist air from the semitropics.

Air (atmospheric) pressure. The pressure of the air at sea level, approximately 15 pounds per square inch.

Alchemy. The medieval science that assumed that base metals could be converted to gold.

Alloy. A solid mixture of metals, such as steel.

Alpha rays. Positively charged particles given off by radioactive substances.

Alternating current. A current that flows first in one direction and then reverses and flows in the opposite direction.

Altimeter. An instrument that measures the height of a plane above the ground.

Ammeter. An instrument for measuring an electric current in a circuit.

Ammonite. Extinct mollusk of the Mesozoic era whose shell resembled a coiled spring.

Ampere. The unit for measuring the flow of an electric current.

Amphibians. Animals that are hatched from eggs in water and develop into land animals; the first animals to live on land.

Amplitude modulation (AM). Varying of the intensity of radio waves according to the sound variations to be broadcast.

Anemometer. An instrument that measures wind velocity.

Anode. The positive terminal in a vacuum tube or electric cell.

Anticyclone. A large whirlpool of air at high pressure moving clockwise.

Archeozoic era. In the earth's history, the period of earliest life.

Armature. Coils of insulated wire supported on a shaft that revolves in a magnetic field, used to induce an electric current.

Astigmatism. An eye defect in which the surface of the cornea is irregularly curved, causing a blurred image.

Atmosphere. The air surrounding the earth.

Atmospheric (air) pressure. The pressure of the air on all surfaces; at sea level, about 15 pounds to the square inch.

Atom. The smallest particle of an element that can take part in a chemical reaction.

Atomic weight. The relative weight of an atom compared with the weight of the oxygen atom as 16 or of the hydrogen atom as 1.

Audiometer. An instrument that measures human hearing.

Barometer. An instrument that measures atmospheric pressure.

Battery. Two or more electric cells connected to form a unit.

Beaufort Scale. Scale from 0 to 12 for measuring wind velocity.

Bernoulli effect. The decrease in the pressure of a rapidly flowing gas or liquid as it passes through a constriction.

Bessemer process. A process of making steel in which a blast of air is sent through molten iron to remove the impurities.

Beta rays. Negatively charged particles emitted by radioactive substances.

Boiling. The process of changing from a liquid to a gas throughout a liquid.

Boiling point. The temperature at which vaporization takes place throughout the liquid; the boiling point of water is 100° C. or 212° F.

British Thermal Unit (B.T.U.). The amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

Calorie. The amount of heat required to raise the temperature of one gram of water one degree centigrade.

Candle power. The measurement of illumination in terms of the illumination of the standard candle.

Capillary. Hairlike.

Carbon arc. Light produced by using two carbon rods as terminals of an electric circuit.

Carbon dioxide cycle. The circulation of carbon dioxide from air to plants, animals, and back to air.

Carboniferous. The geologic period during which the vegetation grew that formed the coal seams.

Catalyst. A substance that speeds up a reaction but is not itself affected chemically.

Cathode. The negative pole or filament in a cell.

Cathode ray. A stream of electrons.

Cenozoic era. In the earth's history, the period of recent life, in which we are now living; it began about 50,000,000 years ago.

Centigrade thermometer. The thermometer on which the freezing point of water at sea level is 0° and the boiling point 100°.

Chemical change. A change in which the substance formed by the combination of two or more elements has no visible signs of the elements composing it.

Cirrus cloud. A high, thin cloud consisting of ice crystals.

Climate. Average weather conditions in an area over a period of years.

Clinical thermometer. The thermometer used to determine the temperature of the human body; its range is between 92° and 108°.

Color-blindness. Inability to distinguish certain colors, such as red from green.

Combustion. Combination of a substance with oxygen, giving off light and heat.

Comet. A heavenly body having a head and a long tail which travels around the sun.

Components of a force. The forces into which a single force can be resolved.

Compound. A substance formed when atoms of two or more elements are linked together chemically.

Conduction. Transference of heat from molecule to molecule in a substance.

Conductor. A substance which transfers heat and electricity well.

Conglomerate. A rock formed from cemented pebbles and gravel.

Conservation. Preserving natural resources, such as soil, water, forests, etc.

Constellation. A group of stars that seem to form a figure or pattern.

Contour plowing. A method of soil conservation in which furrows are plowed to follow the curvature of a hill rather than up and down the hill.

Convection. The transference of heat by means of currents.

Cracking (of petroleum). The process of breaking up kerosene molecules to obtain gasoline.

Cumulus clouds. Large, fluffy clouds that develop into thunderstorms.

Cyclone. A whirlpool of air at low pressure moving counterclockwise.

Decibel. Unit for measuring the loudness of sounds.

Decomposition. The separation of a compound into simpler substances.

Delta. Sediment carried by a river and deposited at its mouth in a form resembling a triangle.

Destructive distillation. Decomposition of a complex substance by heat and the condensation of some of the vapors.

Dew. Water that has condensed on to objects on the ground, usually at night.

Dewpoint. The temperature to which the atmosphere must be cooled to produce condensation.

Diatoms. Microscopic plants which are the source of the oil in deposits on the sea floor.

Diesel engine. An internal-combustion engine that burns oil.

Diffusion. The mixing of molecules of different substances resulting from the movement of molecules.

Dinosaur. An extinct giant reptile of the Mesozoic era.

Diode. A vacuum tube used to rectify alternating current to direct current.

Direct current. A current that flows always in the same direction.

Distillation. Boiling a liquid and condensing the vapor to obtain the pure liquid.

Doldrums. The region on the earth between 10° N. and 10° S. in which there is little or no wind.

Dry ice. Solid carbon dioxide having a temperature of −80° C.

Dust-cloud theory. One of the theories that explain the origin of the solar system.

Dynamo. A machine that converts mechanical energy into electrical energy.

Eclipse. The shutting-off of the light of the sun from the earth by the moon or from the moon by the earth.

Edison effect. The "boiling out" of electrons from a hot filament.

Efficiency. In a machine, the ratio of useful work output to work input.

Effort. In a machine, the force exerted to do work.

Electrical circuit. The path of an electric current from one terminal of a cell or generator through an electrical apparatus to the other terminal.

Electric generator. A machine that converts mechanical energy into electrical energy.

Electricity. A form of energy due to a flow of electrons between positively and negatively charged substances.

Electromagnet. An iron rod magnetized by an electric current flowing through the coil of wires wound around it.

Electromotive force. The force that causes an electric current to flow.

Electron. The negatively charged particle in an atom.

Electronics. The field of physical science in which electrons are used under controlled conditions.

Electroplating. Depositing a coating of one metal on another by electrical means.

Element. A substance whose atoms are all of one kind; it cannot be decomposed by chemical treatment.

Energy. Capacity for doing work.

Engine. Any device that converts the energy of fuel into mechanical work.

Erosion. The wearing-away of rock surfaces and removal of loosened material.

Evaporation. The escape of molecules from a liquid into the space above the liquid.

Expansion. Increase in size (length, area, or volume).

Fahrenheit thermometer. The thermometer on which the freezing point of water at sea level is 32° and the boiling point 212°.

Fault. In geology, a fracture on the earth in which layers of rock slide up or down along the break.

Firedamp. An explosive gas, chiefly methane, present in coal mines.

Fluorescence. The emission of white light by a chemical, such as zinc sulfide, absorbing radiations from mercury vapor.

Focal length. Distance from mirror, or center of lens, to the principal focus.

Fog. Warm moist air near the ground cooled by contact with a cold land or water surface; resembles a cloud.

Fold. In rocks, a bending due to pressure.

Foot-candle. The unit for measuring illumination; the illumination of a surface one foot from one standard candle.

Foot-pound. A unit for measuring work, expressing the force and the distance through which it moves.

Force. A push or pull.

Fossils. Bones, shells, or impressions in rocks of animals or plants that lived in past ages.

Fractional distillation. The process of separating a mixture of liquids into fractions by boiling and distilling the fractions.

Frequency modulation (FM). Varying of the frequency of radio waves according to the sound variations to be broadcast.

Friction. The rubbing-together of two substances; the resistance of the substances produces heat and reduces efficiency.

Front. Boundary between a cold-air and a warm-air mass.

Frost. Moisture that condenses on the ground below the freezing point.

Fulcrum. In a lever, the point about which motion occurs.

Fuse. An alloy with a low melting point used in an electric circuit to break the circuit when an excessive current flows through it.

Galaxy. The concentration of millions of stars, such as the Milky Way.

Gamma rays. Rays given off by radioactive substances; they have no electric charge.

Geiger counter. A device for detecting radioactive substances.

Generator. A machine that converts mechanical energy into electrical energy.

Geyser. A spring of boiling water or steam from the interior of the earth.

Glacier. A slowly moving mass of ice formed on mountains where snowfall exceeds melting.

Gravitation. The force by which every body in the universe is attracted to every other body.

Hail. Precipitation in the form of small pieces of ice formed when raindrops are frozen at high altitudes during a thunderstorm.

Heat. A form of energy.

Heat of combustion. The number of B.T.U. released when one pound of a substance is completely burned; the number of B.T.U. released when one cubic foot of a gas is burned.

Heat of condensation. Heat given off when steam condenses.

Heat of vaporization. The heat energy required to change a specific amount of liquid to vapor.

High. An anticyclone; a whirlpool of air at high pressure, generally bringing fair weather.

Horse power. A unit of measurement of power; 550 foot-pounds of work per second.

Humidity. Moisture in the atmosphere.

Hurricane. An atmospheric disturbance of low pressure that originates over water near the equator and is accompanied by violent winds.

Hydrocarbon. A compound of hydrogen and carbon.

Hydroelectric power. Electricity obtained when water power is used to turn the rotors in generators.

Iceberg. A huge moving mass of ice that separates from a glacier and reaches the sea.

Igneous rock. Rock that was originally matter molten by the heat of the earth's interior.

Image. The picture of an object produced when light from the object is reflected by a smooth, shiny surface or is refracted by a lens.

Incandescent. White-hot.

Incidence, angle of. The angle between the incident ray and the perpendicular to the surface.

Induced current. Production of an electric current by moving a conductor in a magnetic field.

Insulator. A substance in which electrons cannot move freely; hence, a poor conductor of electricity and heat.

Internal-combustion engine. An engine in which pressure to do work is obtained by the explosion of a mixture of fuel and air inside a cylinder.

Intrusion. A horizontal deposit under the surface of the earth formed by the spreading of molten rock.

Invertebrates. Animals without backbones.

Ionosphere. Layer of air high above the earth, which conducts electricity and transmits radio waves over long distances.

Isobars. Lines on a weather map connecting points having the same barometric pressure.

Kilowatt-hour. Unit for measuring electric energy; 1.34 horsepower-hour.

Kindling temperature. The temperature to which a substance must be heated before it starts to burn.

Latent heat of vaporization. The heat energy of vapor, equivalent to the heat energy required to change a given quantity of liquid to vapor.

Latitude and longitude. Latitude is the number of degrees north or south of the equator; longitude, the number of degrees east or west of Greenwich, England.

Lava. Molten matter from a volcano.

Levee. Sediment deposited along the banks of a river.

Light. A form of radiant energy.

Light-year. The unit of measurement for the distances of stars from the earth; the distance that light travels in a year.

Loran. Long-range navigation; a means of determining position at sea or in the air from signals sent by a pair of radio stations working together.

Low. A cyclone; a whirlpool of air at low pressure, generally bringing stormy weather.

Machine. Any device that aids man in doing work.

Magnet. An iron or steel object that attracts iron or steel.

Magnitude. In astronomy, the apparent brightness of a star.

Manometer. An instrument that measures gas pressure.

Mechanical advantage. The ratio of the resistance offered by a machine to the effort applied to the machine.

Mesozoic era. In the earth's history, the period of middle life.

Metagalaxy. The known universe, consisting of many galaxies.

Metamorphic rock. A rock that has been changed by chemical action and pressure.

Meteor. A piece of rock or dust that enters the earth's atmosphere at great speed and becomes glowing hot because of the resistance of the air.

Meteorite. A meteor that reaches the earth.

Milky Way. A broad band in the sky consisting of a great many stars comparatively close together.

Mixture. A substance formed by the mixing of two or more ingredients.

Molecule. The smallest particle of an element or a compound that can exist by itself.

Monsoon. A seasonal prevailing wind that blows from one direction part of the year and from the opposite direction the rest of the year.

Moraine. Stones, boulders, clay, and other matter deposited by melting glaciers.

Motor. A machine that converts electrical energy into mechanical energy.

Nebula. A hazy patch in the sky consisting of a mass of gas, made luminous by the radiation of nearby stars.

Nitrogen. The gas that makes up about 78 percent of the air.

Neutron. An uncharged particle in the nucleus of an atom.

Nuclear energy. Energy obtained by splitting the nucleus of an atom; atomic energy.

Nucleus of an atom. The core of an atom; it has a positive charge.

Occluded front. A meteorological situation in which a warm-air mass is wedged off the ground between two cold-air masses.

Octane rating. Designation of the antiknock qualities of a gasoline.

Ohm. The unit used to measure the resistance in an electrical circuit.

Open-hearth process. The most common process for making steel.

Ore. Material that is mined because it contains valuable metal.

Overtones. The tones above the fundamental produced when a string or instrument vibrates at more than one frequency.

Oxidation. A combination with oxygen.

Oxide. A compound of oxygen and another element.

Oxygen. A chemically active element essential to the reactions of burning; it makes up about 21 per cent of the air.

Paleozoic era. In the earth's history, the period of ancient life.

Phlogiston. The substance which in the Middle Ages was believed to cause fire.

Photosynthesis. In plants the manufacture of sugars and starches from carbon dioxide and water by chlorophyll in the presence of light.

Pitch. The quality of a sound due to the number of vibrations per second.

Planet. One of the nine heavenly bodies that revolve around the sun.

Polaris. The North Star, which is almost exactly over the North Pole.

Power. The rate at which work is done; that is, the ratio of work to time.

Precipitation. Rain, snow, hail, etc., that descend on the earth from the atmosphere.

Prevailing westerlies. The winds that blow from the southwest between latitudes 30° and 60° of the Northern Hemisphere, and from the northwest in the same latitudes of the Southern Hemisphere.

Proterozoic era. In the earth's history, the period of primitive life.

Proton. A positively charged particle in the nucleus of an atom.

Radar. Radio direction finding and ranging. A device that locates objects through dense fog and clouds by means of radio waves of extremely high frequency.

Radiant energy. Energy that travels through space in straight lines in all directions from its source, as, for example, light and heat from the sun.

Radiation. Transference of light, heat, and energy through space.

Radioactivity. Ejection of rays (alpha, beta, and gamma) from the nuclei of radioactive atoms.

Radiometer. An instrument that indicates the presence of radiant heat.

Radiosonde. Apparatus carried by a balloon to the stratosphere to measure air conditions.

Radon. The gas formed in radioactivity which makes the surrounding air a conductor of electricity.

Reactor. An atomic furnace used for the fission of uranium.

Reflection, angle of. The angle between the reflected ray and the perpendicular to the reflecting surface.

Refraction. The bending of a ray of light as it passes from a substance of one density to a substance of a different density.

Relative humidity. Ratio of the actual amount of vapor present in the atmosphere at a given temperature to the maximum amount of vapor the atmosphere can hold at that temperature.

Resistance. In a machine, the force to be overcome.

Respiration. The slow burning, or oxidation, of food in the cells of an animal body.

Satellite. In the solar system, a small body revolving around a larger one, as the moon around the earth.

Saturated solution. A solution in which the solvent has dissolved as much of the solute as it can dissolve at a particular temperature.

Sedimentary rock. Rock formed from the sediment carried by water from the land and deposited in bodies of water.

Seismograph. An instrument that records earthquakes.

Short circuit. A circuit formed when an electric current flows through a small resistance rather than through the regular circuit of larger resistance.

Solar system. The sun and the planets and their satellites that revolve around the sun.

Solution. A mixture in which one substance is dissolved in another. The liquid is the *solvent;* the dissolved substance, the *solute.*

Sonar. Sound and ranging. A device for detecting a submerged object by means of the reflection of sound waves.

Sound. A form of energy; vibrations that reach the ear.

Spectroscope. An instrument that separates the colors in light.

Spectrum. The band of colors formed when light passes through a prism.

Spontaneous combustion. Burning that is due to chemical action within a substance, not to the application of heat to the substance.

Stalactite and stalagmite. Formations of calcium carbonate resembling icicles on the ceiling and floor of limestone caves.

Standard time. Uniform time established by law and custom for all places located within the same time zone. Each zone covers 15 degrees of longitude, and the time varies one hour from zone to zone.

Star. A heavenly body that shines because of its own incandescence. Because of its very great distance from the earth it appears not to be moving.

Static. Electricity produced by sparks.

Stratosphere. The outer layer of atmosphere about 40,000 feet above the earth's surface in which there is no weather.

Strip cropping. Planting alternate rows of grain crops and other crops. The fibrous roots of the grain prevent water from running off.

Sunspots. Cooler places on the surface of the sun that appear as dark patches.

Tachometer. An instrument that measures the speed of an airplane engine.

Talus. Rock debris at the foot of a mountain.

Temperature. The degree of hotness of a substance as measured by a thermometer.

Tempering. Gradually cooling a metal, such as steel, to produce the desired qualities of hardness, strength, and flexibility.

Terracing. A method of soil conservation in which a long slope is broken into shorter slopes to prevent soil from being washed away.

Thermostat. An automatic device for controlling temperature, based on the different rates of expansion of two metal strips joined together.

Tidal theory. The most commonly accepted theory of the origin of the solar system.

Tide. The regular rise and fall of the water along the shores of oceans and other bodies of water due to the attraction of the moon and the sun.

Till. Clay, sand, etc., laid down by glaciers.

TNT. Trinitrotoluene, a high explosive.

Tornado. A small atmospheric disturbance of low pressure, starting on a very hot day and accompanied by winds of high velocity that are highly destructive.

Trade winds. Prevailing winds in the belts 10°–25° north and south of the equator. In the Northern Hemisphere they blow toward the equator from the northeast, in the Southern Hemisphere from the southeast.

Transformer. A device that changes the voltage of an alternating current. *Step-up transformer* increases voltage; *step-down transformer* reduces voltage.

Transmutation. Changing one substance into another, as converting a base metal into gold.

Trap. In the earth, an obstruction that encloses oil.

Trilobite. An extinct Paleozoic animal whose body was divided into three lobes.

Triode. A vacuum tube with a grid that controls current and voltage; it is used in amplifiers.

Tropopause. A thin region of the atmosphere between the troposphere and the stratosphere.

Troposphere. The thin shell of air surrounding the earth in which weather changes take place.

Turbine. An engine that is set in rotation by water or steam pressure or by the combination of steam and the internal combustion of fuel gases.

Ultrasonics. Sounds with frequencies higher than can be heard by the human ear.

Unconformity. Irregular line of separation between newer and older rock strata.

Vapor. The gaseous state of a substance, usually brought about by boiling or evaporation from the solid or liquid form of the substance, as steam from water.

Van de Graaff generator. A machine for producing artificial lightning and high voltages for X-ray machines and atomic research.

Vertebrates. Animals with backbones.

Volcano. An opening in the earth's surface through which red-hot molten rock escapes.

Volt. Unit used to measure electromotive force.

Voltage. Electric force that causes a current to flow.

Voltmeter. An instrument for measuring drop in voltage.

Water cycle. Repeated evaporation and condensation in the atmosphere.

Watt. Unit of measurement of electric power.

Weather. Day-to-day changes in meteorological conditions.

Weathering. The wearing-away of rocks by wind, rain, and sun. *Mechanical weathering* is due to pressure; *chemical weathering,* to carbonic acid.

Work. The product of a force and the distance through which the force moves.

X rays. Shortest waves in the electromagnetic spectrum; able to penetrate opaque materials.

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